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HANDLE VIA BYEMAN CONTROL SYSTEM ONLY - HEXAGON / GAMBIT

Imagery Resolution Assessment and Reporting Standard (IRARS) for Tribar Resolution

JUNE 1974

DIRECTORATE OF SPECIAL PROJECTS
OFFICE OF THE SECRETARY OF THE AIR FORCE

BYE 15313-73

Classified by BYE-1
Exempt from general declassification
Schedule of Executive Order 11652
Exemption category [ss 5B(2)]
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Approved for Release: 2018/07/31 C05106617

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Published By

HQ AIR FORCE SPECIAL PROJECTS PRODUCTION FACILITY

Approved for Release: 2018/07/31 C05106617

IMAGERY RESOLUTION ASSESSMENT AND REPORTING STANDARD (IRARS) FOR TRIBAR RESOLUTION

11 July 88

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JUNE 1974

(Revised in April 1976)

This report consists of 131 pages. Cy / of 53 Cys

BYE 15313-73

IRARS
TRIBAR RESOLUTION STANDARD

PUBLICATION REVIEW

This standard has been reviewed and approved by the Imagery Resolution Assessment and Reporting Standard Task Force (IRARS-TF).

HAYDEN B. PEAKE, Lt Colonel, USA
NRO. Chairman IRARS-TF

IRARS
TRIBAR RESOLUTION STANDARD

FOREWORD

BACKGROUND

The Imagery Resolution Assessment and Reporting Standard Task Force (IRARS-TF) was formed in April 1973 by the Director of the National Reconnaissance Office (DNRO)* to prepare standards for determining resolution of imagery within the National Reconnaissance Program (NRP).* The initial problem for the task force was to decide which of the several methods currently used to determine resolution should be first standardized. Tribar resolution was selected because it is the most commonly used and misused.

Standards for other techniques, e.g., visual edge matching (VEM), are in preparation and will be published in late 1974. Resolution measuring techniques still in the research and development stage are under consideration by the task force and will be included when and if appropriate.

NEED FOR TRIBAR STANDARD

More than 20,000 tribar resolution target readings are made in support of each HEXAGON mission. Approximately 500 readings are required for postflight evaluation of each GAMBIT mission. While the number of readings may be reduced as new resolution determination procedures are developed, the current level of dependence on tribar resolution data will continue for the foreseeable future. Among their applications, tribar resolution data influence hardware acceptance, performance fees, estimates of system performance, and statements of image quality. Thus, the data are important to the program offices, contractors, and exploitation community alike. It is therefore imperative that the reported values be accurate, precise, and independent of reader, equipment, and organizational bias. It is not too strong a statement to say that these conditions have not always been met; this standard is intended to overcome this situation.

MEASURE OF SUCCESS

Any task to be performed or problem to be solved should make clear at the outset the nature of the solution anticipated. The solution in this case has three elements. The first is short-term and procedural - common resolution assessment and reporting procedures to be applied throughout the community. The second is a consequence of the first and long-term by nature - a reduction in the frequency of misinterpretation and improper applications of resolution and the introduction of new and more versatile techniques. Last and perhaps most important, the resolution reader should acquire a feeling that he understands the concepts and constraints, pitfalls and benefits, associated with the assessment, reporting, and application of resolution data. In this context, then, it is clear that publication of this document, per se, does not provide the entire answer; both consistent application and informed management in the long term are essential to success.

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* These terms, when used alone, are classified Top Secret in the Byeman Control System.

ORGANIZATION OF THE TRIBAR STANDARD

The tribar standard is written for a wide audience. Section I is intended primarily for those individuals who are more concerned with concepts and key issues which must be understood in order to apply the resolution results properly. For those more technically oriented, but new to the subject, the tutorial on resolution in Section II should be helpful. The remaining sections deal with the specifics of tribar resolution assessment, reporting, and training.

IRARS-TF PARTICIPATION

The IRARS Task Force participants and organizational affiliations are listed on page v. Readers with comments and/or criticism are encouraged to contact their representatives or other appropriate task force members. This standard will be reviewed and updated periodically by the IRARS-TF. In this way the IRARS can become responsive to the requirements of the entire NRP community.

SUGGESTED READING

There are many available literary sources for theoretical and applied technical information concerning the subject of image quality. Some of the primary sources which are suggested for further reading or reference are listed below:

A. Cox, Arthur; "Photographic Optics," Focal Press, London, 1966. A good introduction to the basic optical image quality concepts including MTF and resolution.

B. Brock, Gerald; "Image Evaluation," Focal Press, London, 1970. Considered by many as the best single text on the subject. Presents technical information and application rationale in a manner which can be understood by anyone with interest and background in basic physics.

C. Mees, C. E. K.; "Theory of the Photographic Process," Third Edition, Macmillin Company, London, 1965. The best treatment of the theory in print.

D. Rickmers and Todd; "An Introduction to Statistics," McGraw Hill, New York, 1967. A good at-home treatment of the concepts and pitfalls of statistical analysis and experimental design.

E. Selwyn, E. W. H., and Tearle, J. L.; "The Performance of Aircraft Camera Lenses," Proceedings of the Physical Society, 1 Sep 1946, Vol 58, Part 5, #329, London. Gives a good picture of the image quality problem of 30 years ago.

IRARS
TRIBAR RESOLUTION STANDARD

TASK FORCE MEMBERS

NATIONAL RECONNAISSANCE OFFICE (NRO)

Lt Col H. B. Peake (IRARS-TF Chairman)
Lt Col R. J. Prochko

DEFENSE INTELLIGENCE AGENCY (DIA)

P. Labar

CENTRAL INTELLIGENCE AGENCY/OFFICE OF DEVELOPMENT AND ENGINEERING (CIA/ODE)

R. J. Kohler
[redacted]

COMIREX

[redacted]

NATIONAL PHOTOGRAPHIC INTERPRETATION CENTER (NPIC)

[redacted]

SECRETARY OF THE AIR FORCE SPECIAL PROJECTS (SAFSP)

Lt Col G. D. Baetz
Captain R. E. Lacroix
Major D. F. Berganini

ROME AIR DEVELOPMENT CENTER (RADC)

J. L. Roberts

ENGINEERING TOPOGRAPHIC LABORATORIES (ETL)

J. O'Dell

DEFENSE MAPPING AGENCY AEROSPACE CENTER (DMAAC)

J. W. Smith

INTELLIGENCE COMMUNITY STAFF (IC STAFF)

[redacted]

(b)(3)

HQ AIR FORCE SPECIAL PROJECTS PRODUCTION FACILITY (AFSPPF)

Lt Col L. M. Martucci
2d Lt D. A. Turbide

CONSULTANTS

[redacted] (Itek)
[redacted] (EKC)
[redacted] (EKC)
E. P. Myskowski (P-E)

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SECTION I

SUMMARY

1.1 INTRODUCTION

This section provides an overview of the IRARS Tribar Resolution Standard. It is intended to establish a common context within which resolution may be discussed, to identify the circumstances under which resolution can be legitimately applied, and to discuss the kind of questions it can and cannot be expected to answer. After some brief comments on the need for a standard and the concept of resolution and its statistical nature, the principal sections are discussed in order to clarify their role.

In this, the initial IRARS document, the procedural portions deal entirely with tribar* resolution. Even though use of this form of resolution as a quality measure is an established long standing operational precedent, its determination and application within the NRP were found to vary from program to program. Under these circumstances, interpretation of resolution values is ambiguous at best. It was for these reasons that tribar resolution was selected as the first type of resolution to be addressed in the IRARS-TF program to standardize image quality assessment in the NRP. Because tribar resolution is not without some very practical technical limitations, the search for alternative methods has been continuous. This section concludes with a short review of alternative techniques under consideration for standardization in the future.

1.2 GENERAL COMMENTS

1.2.1 Need for a Resolution Standard

One of the first questions asked by a manager, scientist, or technician concerned about the quality of the image produced by a photo-optical system is, "What is its resolution?" Whether the system is still on the drawing boards or in routine operation, resolution, in one of its several forms, is the most frequently employed single numerical indicator of performance. Unhappily, resolution is also frequently misunderstood, or worse, improperly applied by the system designers, operators, and users alike.

In the past when each photo satellite system had a unique mission, when performance was far below the theoretical best and when, in one sense, any coverage at all was considered good, the consequences of an inaccurate estimate of resolution were not severe. However, as technology improved so did the performance and the cost of each component of the photo-optical system. Today the concern is no longer a question of simply returning imagery from space or even whether aircraft can be seen on an

* The term "tribar" refers to the type of resolution test target placed in the object and recorded in the resultant image which is used to determine system resolution values.

airfield; rather, the issue is whether one particular model of aircraft, vehicle, or radar can be distinguished from another. Photo satellite systems which produce the high resolution imagery necessary to permit such discrimination are far more complex and costly than their predecessors. Where high resolution was once measured in feet, today it is measured in inches. As a consequence one must have some reliable way of more accurately determining the resolution of the system while under design and in operation. It is therefore imperative that resolution be specified in a manner which is technically correct, sensitive to small detail, applicable to all systems of interest, and which has a common meaning to all concerned, i.e., image quality determination and specification should be standardized.

1.2.2 Resolution As a Concept

In order for any standard to be successful, the terminology and concepts involved must be clearly defined and subsequently understood. (The glossary describes the main terms necessary to understanding resolution - other terms are defined as they are introduced.) Resolution is conceptually attractive because the meaning of the term is intuitively clear, i.e., what is the size of the objects that can be seen in the image? Equally important is the fact that the objects or detail that cannot be seen also indicate the capability of the system. Implicit in these distinctions is the concept of a limiting resolution or the smallest detail that can be observed in the image. Once this limit or boundary is known the system capabilities can be described. In a generic sense, the term resolution is a photo-optical system attribute which specifies the size of the smallest objects which will be recorded, and thus that one will see, in the image. It is clear that knowledge of this value is vital to both system designers and photo-interpreters. In fact, resolution is the only numerical image quality measure employed by both the collection and exploitation elements of the intelligence community. In this sense, it is an interface quality parameter which links the designer, the engineer, and the interpreter thus allowing them to communicate and discuss system performance in terms understandable to all. It is this rationale that underlies the ubiquitous use of the concept.

1.2.3 Statistical Nature of Resolution

While in concept resolution specifies the limiting size of objects recorded, in practice it is not that straightforward. The resolution value obtained depends in a very complex manner upon several operational factors whose combined behavior can be modeled only by statistical methods. Conditions of weather, relative image motion (which can depend on as many as 50 individual variables), film response, and others all contribute to the final resolution value obtained. The principal variables and techniques for dealing with them will be discussed in Section II. The key point here is that any resolution value is a statistical estimate whose accuracy and precision are dependent on how well the system variables themselves can be controlled. The situation is analogous to that of determining the miles per gallon consumed by a given automobile. The measured value will vary depending on driving conditions, engine performance, fuel type, the driver, etc. Moreover, determining the contribution of each to the mileage figure is not a trivial matter. This brings us to another key point regarding resolution. It too is ultimately determined by a human observer making a judgment about how well a particular target can be seen in an image; however, observers do not always repeat their judgments exactly or agree among themselves. Exact knowledge of all physical system variables, even if known, would not eliminate the inherent human variation in determining resolution values. Although techniques are under development to automate the decision now made by the human, such procedures are not sufficiently well defined to be used operationally.

From the manager's point of view, the primary technical attribute of resolution is that it is a statistical parameter, not a fixed value. Thus, any value of resolution has a degree of error associated with it and the manager must take action to make certain that the nature of the error is known. While some knowledge of statistics may be helpful, it is not essential - the scientists and technicians are paid to provide this service. Common sense is the prerequisite; a manager must know that error exists and inquire as to its value and impact on the system. For example, resolution of 10 inches has no meaning unless the conditions and likelihood of occurrence are known and reported. Further, if the error associated with this value is ± 8 inches one should conclude that the value reported is not very accurate and that the quality of the imagery concerned is really not known very well. In this case, the manager should instruct his staff to identify the sources of error and, if possible, reduce them (techniques for analyzing and controlling resolution reading variability are covered in Appendix C). If this cannot be done, there is no alternative but to accept the fact that for the system concerned resolution cannot be specified with high accuracy. It is for this type of reason that reporting procedures were included in the standard - a single resolution value alone is not enough.

1.2.4 The Criterion of Reasonable Confidence

The assessment of resolution is by definition an estimate of the smallest detail recorded, i.e., it indicates a limiting performance characteristic of the system. The decision which determines this limit in terms of resolution is made by the resolution reader. To assist him, he is provided criteria (see paragraph 3.3.1) for deciding when a tribar image is resolved. He is told that his decision should be between complete confidence and no confidence at all that the tribar is resolved. While this may at first sound arbitrary and imprecise, experience has shown it to be a good and reliable criterion. The rationale for this approach is that there is important information beyond the resolution level where the tribars are read with certainty. Consequently, in order to indicate the limiting ability of the system, a judgment of tribar resolution beyond this point is justified.

1.3 DISCUSSION OF CONTENTS

1.3.1 Resolution Tutorial

It was asserted above that, conceptually, resolution is a unique attribute of a particular system. This was followed by the key point that a resolution value is statistical in nature; i.e., can never be known exactly. Section II of the standard is a tutorial which develops the basic technical background necessary to understand these assertions. It does assume some familiarity with the subject however, and references are provided for the beginner. The section begins with definitions of each form of resolution. These are followed by a discussion of photographic resolving power as a concept and a discussion of the technical factors affecting system resolution, including the nature of their impact on the final resolution value. The section concludes with a review of the advantages and disadvantages of resolution in satellite reconnaissance.

1.3.2 Resolution Limitations and Constraints

Certain resolution limitations and constraints should be kept in mind while reading and using this standard. The requirement for a special target in the object area to be photographed by a satellite in order to subsequently determine system resolution is costly, constrained to domestic coverage, subject to weather conditions, and provides a minimal number of samples from which resolution can be determined. In addition, when considering the inherent danger of characterizing any complex system by a single number, the fact that tribar targets do not look like most of the other photographed objects, and that for a given object the quality of its image(s) may vary with look angle, lighting conditions, scene contrast and other factors, then from all these factors one can see that resolution is not the total answer.

These inadequacies notwithstanding, tribar resolution is very useful and is frequently used as a measure of image quality throughout the NRP. To optimize the chance for useful results one should obtain as many samples as possible, know the test conditions, make repeated readings of the tribar image, have well trained personnel, and never accept a single resolution value as an indication of characteristic performance.

In short, the application of resolution values as a measure of system image quality requires experience and knowledge about the conditions under which the values were determined. Without this information, completely misleading results can be obtained.

1.3.3 On the Definitions of Resolution

The term "resolution" is generic and often used, as it was above, to imply one of the following specific forms: resolving power (RP), ground resolution (GR), or ground resolved distance (GRD). Each of these terms represents a specialized form of the basic concept which relates to separating, making visible, or distinguishing small detail.

Ground resolution, by definition expressed in linear distance units, is determined solely on the basis of the judgment of an experienced photointerpreter or phototechnologist. He observes the image in question and makes a professional judgment as to the size of the smallest detail he can see, e.g., an antenna element, tank track width, or gun tube diameter.

Ground resolved distance (GRD) requires the use of a special ground target composed of three alternating black and white bars of known dimensions. This "tribar" target is placed in the object area and recorded by the photo optical system concerned. The width of the smallest element (one black and one white bar) of the target that can be observed in its image is defined as the GRD. At present, this is the most commonly used measure for specifying system image quality. (It does have some drawbacks which will be discussed later).

Resolving power (RP) is also determined from a tribar target but it is used primarily in laboratories for testing optical systems and films. In this form, resolution is expressed in terms of the number of cycles recorded in one millimeter (cycles/mm) rather than in linear units; the greater the number of cycles/mm the better the quality.

In summary, each type of resolution has a specific meaning and application. While it is not uncommon to see and hear the terms used interchangeably, such misuse only adds to the confusion. Section II of this standard specifies the procedures and conditions to be employed for each kind of resolution.

1.3.4 Factors Affecting Resolution

The following factors are discussed in Section II, paragraphs 2.3 and 2.4, as the principal ones to be considered when assessing resolution in any type of photo-optical system·

A. Optics.

B. Uncompensated image motion.

C. Film.

D. Film processing.

E. Exposure.

F. Focus.

G. Contrast.

H. Scene content.

I. Geometric relationships.

Each one can be characterized mathematically from design data by direct measurement techniques (e.g., optical quality) or from statistical performance data (e.g., image motion). Thus, they can be included in computer simulations which predict image quality. In any case, three important points should be kept in mind. First, when these factors operate at their optimum values, resolution should be at its best;

hence one must know their operating behavior before characteristic system resolution can be properly assessed. While it requires a good system engineer to explain all the detailed interactions involved, the manager need not be overconcerned with the fine details. Each factor can be described in simple functional terms and one should not accept unnecessarily complicated explanations. Second, an important factor not listed above which also affects the resolution value obtained is the human observer who makes the resolution assessment. His contribution and the techniques for evaluating his performance are highly significant and will be covered in Section IV. The third point, vital to the understanding of image quality, concerns the fundamental theory of image formation in photo-optical systems and the functional relationship of each factor listed above. The basic measure of performance of any photo-optical system is the extent to which a point of light in the object is recorded as a point in the image. Poor photo-optical systems photograph points as blurry edged blobs. Consequently, the total image is not clear or sharp. Good optical systems form a well defined point image whose darkness, or density, in the negative is directly related to the brightness of the object point. Theoretically, images are made up of many points; the accuracy of the image in depicting the object is a measure of image quality. More technical terms are used in Section II for the representation of light in the image, e.g., point spread function and line spread function. However, the basic concept is the same for all such representations.

1.3.5 Assessing and Reporting Tribar Resolution Data

Assessing and reporting tribar resolution data are the substantive topics of the standard and are covered in Section III. Procedures, criteria, and equipment necessary to assess resolution are discussed in some detail. Where possible guidance is intentionally general in nature so that individual organizations may adopt procedures to meet their operational situation.

It should be borne in mind that correctly assessed resolution values are of little use if they are improperly reported. For example, a particular GRD value has no real meaning unless associated acquisition conditions and measurement data are also reported. Implementation of this standard should avoid that problem in the future.

1.3.6 Reader Training and Calibration

The value of resolution obtained is not only dependent on technical and statistical factors; a well trained human reader is a necessary part of the process. The several studies that led to the writing of this standard demonstrated that resolution reading of the same images by different people and groups of people produced different results. Part of the reason for this inconsistency is point-of-view, i.e., different groups tend to read with different criteria. On the other hand, with proper initial training and periodic refresher training, tribar readings by a variety of people can be within ± 1 element of the average. The procedures in Section IV and Appendix C of the standard are designed to achieve this goal.

This is not a simple task, and substantial effort has gone into establishing a system that will work for the entire intelligence community. A standing resolution reading training committee chaired by AFSPPF has been established. Each IRARS-TF member has provided a representative. A training course with the necessary forms, quality control procedures, and standard tribar images has been developed and is currently undergoing tests before being provided to each member organization. In order for the standard to be successfully applied, each member organization must support this portion of the program by providing training time, personnel, equipment and funds.

1.4 FUTURE ROLE OF THE IRARS-TF

The desirability of overcoming the limitations and restrictions imposed by tribar resolution has been studied for years within and without the NRP. A principal objective of the alternative techniques considered has been to achieve test target independence; i.e., eliminate the need for special targets in the object area in order to determine resolution. The visual edge matching (VEM) technique is the most promising alternative now available. It has been tested thoroughly in the HEXAGON program and now, under the IRARS-TF sponsorship, is being tested with GAMBIT imagery. In essence, one visually matches edges in the image of concern to an edge in a matrix of edges wherein sharpness and contrast vary in a known manner. Another method for estimating resolution is the modulation transfer function/ threshold modulation (MTF/TM) technique. The IRARS-TF is preparing standards for the VEM and MTF/TM techniques. These standards are presently scheduled for publication in late 1974.

Power spectral analysis (PSA) and measures of information content are also under consideration by the TF. Some preliminary experiments on satellite imagery have been performed with encouraging results. The IRARS-TF is sponsoring some basic research on PSA at the University of Arizona in an attempt to better understand the physics involved. The PSA technique operates on the principle that sharp edges in an image diffract more light at greater angles than less sharp or fuzzy edges and that this phenomenon can be correlated with quality. Special equipment and analytic requirements have been developed, but insufficient data are available to permit an estimate as to when the techniques might be ready to be used in the NRP.

The IRARS-TF has been tasked by the DNRO to monitor the image quality projects throughout the NRP. This will help to prevent a recurrence of the disjointed incrementalism which has characterized the progress of the image quality effort in the past.

Through a continuation of the cooperation experienced to date, the execution of appropriate experiments, and the application of innovative management, the elusive subject of image quality will become more consistently understood, interpreted, and applied.

SECTION II

THE CONCEPT OF RESOLUTION

2.1 DEFINITIONS

At the onset, it is important to understand that this document will discuss several terms, each of which relates to the other while retaining its own distinct meaning. The terms are: (1) resolution, (2) ground resolution, (3) resolving power, and (4) ground resolved distance. These terms are often used interchangeably; therefore, it is essential to define and thoroughly understand each.

A. Resolution (R)

Resolution of an optical system or a photographic film or combination thereof refers to its capacity for imaging fine detail. The term resolution refers to either a qualitative or quantitative subjective* estimate. A system may be characterized either as having high or low resolution, or as producing images of some dimensional value(s).

B. Ground Resolution (GR)

Ground resolution, a term used in photointerpretation, is a subjective numerical estimate of the limiting size of ground objects imaged on film. It does not require a test target for its determination and may not equate to ground resolved distance. The degree to which an individual can detect, recognize, and identify ground objects leads to his estimate of ground resolution.

C. Resolving Power (RP)

Resolving power is a numerical value assigned to indicate the capacity of a photo-optical system or film to image fine detail. It is the reciprocal of the minimum test target element dimension expressed in cycles/mm, lines/mm, or the more colloquial "lines." In the test target element illustrated in Figure 2-1, the minimum dimension (bar and space) referred to is the distance (ω) and the resolving power is 100 cycles/mm.

D. Ground Resolved Distance (GRD)

Ground resolved distance is the minimum test target element distance resolved on the ground, e.g., the dimension "ω" in Figure 2-2. Thus, with a system that produces a GRD of 1.0 foot, the smallest bar of the test target that is distinguishable has a physical width of 0.5 foot. In Figure 2-2, "ω" is equal to one foot.

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*The term subjective is used here in the context of a human observer making the estimate of resolution.

TRIBAR TEST TARGET ELEMENT ON FILM

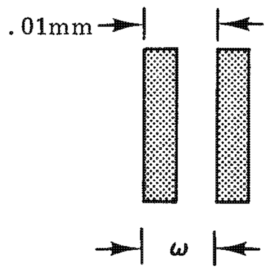


FIGURE 2-1

TRIBAR TEST TARGET ELEMENT ON THE GROUND

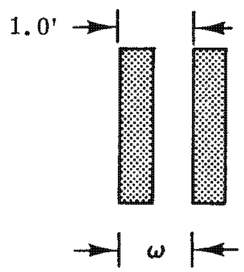


FIGURE 2-2

2.2 PHOTOGRAPHIC RESOLVING POWER

2.2.1 Basic Concepts

The ability of a photo-optical system or film to record fine detail is generally expressed in terms of resolving power. This is not because the resolving power test is necessarily the best or the only possible test but because it is a practical and accepted way of evaluating lenses, films, and/or systems on a quantitative basis.

The concept of resolving power is not, of course, peculiar to photography. It originated in astronomy as a method of describing the ability to separate the images of two, nearby, distinct points of lights, such as double stars. Therefore, resolving power implies a threshold separation of distinct elements. The simplest example of resolution is the just discernible separation of two points, represented as spread functions produced by an imaging system. When a point source is imaged by a lens, diffraction and aberrations cause the image to be an extended spot, not a point. In a sense, the image can be considered to be a mound of light as is shown in Figure 2-3. The distribution of light in this image is referred to as the point spread function. If this image is scanned by a pinhole, the resulting trace, representing the distribution of energy in one direction, would be a cross section of the light mound, see Figure 2-3.

The actual shape of this cross section will, of course, depend upon the direction and position of the scan.

METHOD OF FORMING AND SCANNING A POINT SPREAD FUNCTION
AND A LINE SPREAD FUNCTION

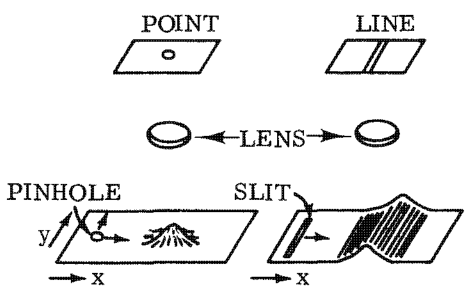


FIGURE 2-3

Figure 2-4 illustrates three cases of resolving power using point objects. In the figure, there are three instances of interaction between two such point spread functions. At the left, two points are so widely separated by distance (α) that they are essentially independent of one another and are clearly resolved. At the right, two points are so close together (separation β) that they blend into what is effectively a single element and are not distinguishably resolved from one another. In the center, two points are close enough to one another (separation δ) that there is some interaction; yet they are still recognizable as separate entities. This threshold condition constitutes a just resolved situation and, in so doing, establishes the resolving power limit for the performance capability of the imaging system. The fundamental concept of resolving power is some expression of a minimum separation distance measurement (δ).

CONCEPT OF RESOLVING POWER USING POINT OBJECTS

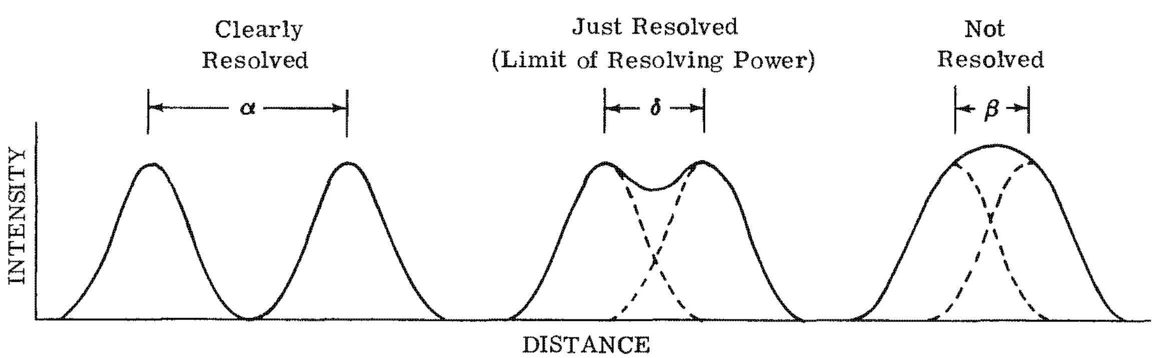


FIGURE 2-4

Because monitoring the resolution of paired points is impractical with real imaging systems, a more manageable element is required. This element is the line, which is an extension of a point in space. A line spread function can be considered in a fashion similar to the point spread function. When a very narrow, bright line is imaged by a lens, the image formed is an extended mound of light. When this line image is scanned by a long, narrow slit in the manner illustrated in Figure 2-3, the resulting trace represents the distribution of light in the image measured along a direction perpendicular to the line and is referred to as the line spread function.

While the foregoing is strictly true for lines of infinitesimal width, in practice a line must have finite width and length and, as such, is no longer really a line but a rectangle or "bar." The concept of resolving power employing bars is shown in Figure 2-5.

CONCEPT OF RESOLVING POWER USING BARS

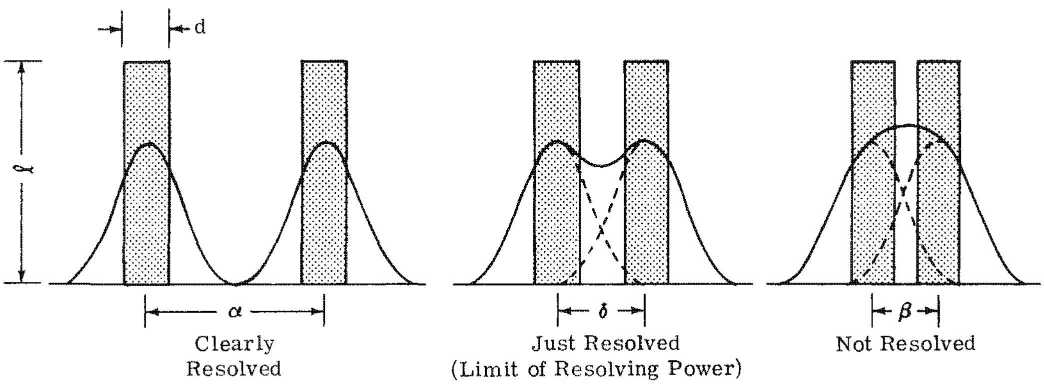


FIGURE 2-5

Figure 2-5 shows bars of length (ℓ) and width (d) in various degrees of separation (α, δ, β) along with their concomitant bar spread functions and resultant traces. The resolving power is characterized by measuring the separation distance (δ) and taking the reciprocal as indicated in Figures 2-1 and 2-2.

2.2.2 Test Target Concepts

It would be extremely cumbersome to test the resolution of a system by successively imaging a single pair of bars at smaller and smaller separation distances. It is simpler to fabricate an array of bar pairs with varying separation distances which can be imaged instantaneously. If each of the pairs is pre-measured and labeled, it is then only necessary to identify in the image the bar pair immediately adjacent to what is thereafter a series of single indistinguishable (merged) bars, and the separation distance (δ) is known. The point beyond which individual bars are not identifiable is called the threshold separation point.

The resolution target is basically an arbitrary design. In the case of high altitude camera systems, in-track (vehicle flight direction) and cross-track (perpendicular to the flight direction) resolution data are desired. Therefore, test targets are designed to provide this information, see Appendix A. Exactly how the test targets are configured in terms of physical placement of the test target elements is more a matter of practical convenience than anything else.

The fact remains, however, that resolving power test targets have to be logically designed and constructed to fulfill the existing requirement. Referring again to Figure 2-5, there is an immediate problem inherent in the configuration shown. That problem is that each bar pair is of different relative geometry. As the separation decreases, the bars become longer relative to their separation, thereby increasing their discernibility. In addition, the distance between the bars relative to their width is an important factor in determining the width of bar that can be resolved. To eliminate these sources of confusion, it is necessary to maintain a constant aspect ratio (length-to-width) in the bar pair array. It then becomes possible to maintain a specified relative separation between the bars, see Figure 2-6.

EXAMPLE OF RESOLVING POWER TEST TARGET ARRAY
ILLUSTRATING CONSTANT LENGTH-TO-WIDTH RATIO

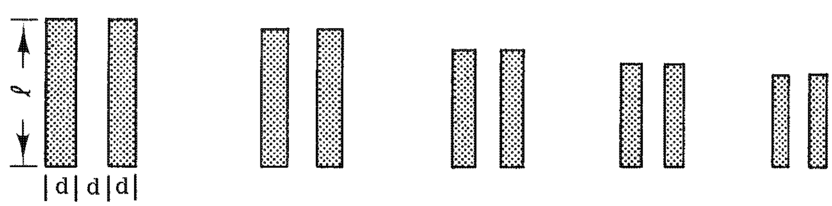


FIGURE 2-6

In Figure 2-6, the aspect ratio has been standardized at 5:1 and the separation distance between bars standardized to be equivalent to the bar width. Any other reasonable arrangement would suffice; but resolution testing in the reconnaissance community has for years been standardized to a 5:1 ratio.

One more modification to the bar target array is necessary to complete the basic concept of resolution targets. To improve the assurance of minimum separation discernibility, more than two bars are used. The standard configuration is three bars composing a test "element" and two or more elements, a test "group." The standard resolution target element sketched in Figure 2-7 is square ($\ell = 5d$). Superimposed on the element in this figure is the just resolved spread function of the bars and the resultant trace. Thus in this standard, resolution is based upon the threshold separation of three bars by two spaces. The minimum separation distance (δ) is the fundamental measure of resolution and can be expressed in a number of ways. From the figure, it is evident that $\delta = 2d$, which is a bar-plus-space equivalent. Resolving power is the reciprocal of δ measured in millimeters, i.e., resolving power

(RP) = $1/\delta$. For example, if δ measured 10 microns, then the resolution would be expressed as 100 mm^{-1}, 100 cycles/mm, 100 lines/mm, or colloquially "100 lines."

FUNDAMENTAL TRIBAR TARGET ELEMENT GEOMETRY
SHOWING THE RESOLUTION THRESHOLD

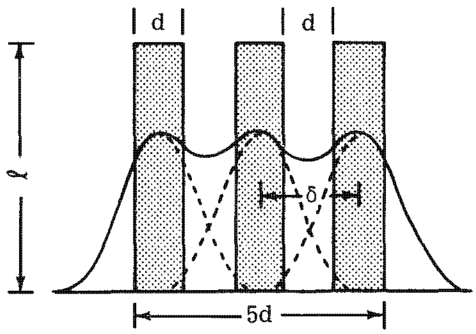


FIGURE 2-7

2.2.3 Test Target (Object) Progression

In the design and construction of a tribar test target, it is necessary to decide how many tribar elements are required and their geometric progression. By choice, the rate of change in bar width of adjacent tribar elements is not linear, but geometric. In other words, the percentage of change is kept constant. In this way, a large range of bar widths can be achieved in a limited number of elements. Because of the practical applications of resolving power expressed in cycles/mm, it is meaningful to refer to spatial frequency as the reciprocal of a bar/space pair width rather than just bar width alone.

A number of geometric series have been used for test target configuration. Most common at the present time are the $\sqrt[6]{2}$, $\sqrt[20]{10}$, and $\sqrt[12]{2}$. The constant percent differences in spatial frequency between adjacent elements for these progressions are: 12% for both the $\sqrt[6]{2}$ and $\sqrt[20]{10}$ targets, and 6% for the $\sqrt[12]{2}$. The USAF 1951 Test Targets have a $\sqrt[6]{2}$ progression. The mobile Controlled Range Network (CORN) tribars are configured in both the $\sqrt[6]{2}$ and $\sqrt[12]{2}$ progressions. The ANSI Standard* is the current document listing the approved specifications for testing the resolving power of films; this publication utilizes the $\sqrt[20]{10}$ progression targets. The existence of various test target configurations is due largely to the different intended purposes of the target originators, based upon the systems concerned. Specific test target configurations are discussed in Appendix A.

*American National Standard for Determining the Resolving Power of Photographic Materials, pH-2.33-1969, Approved July 7, 1969.

2.2.4 Test Target Polarity

Test target polarity is the relationship of the brightness between the bars and surround. It is possible to have either dark bars with brighter surround or bright bars with darker surround. The usual convention is to describe the former as positive polarity and the latter as negative polarity.

Film response to target polarity depends on negative or reversal processing. It is common practice with satellite cameras to employ targets of negative polarity.

2.2.5 Test Target Contrast

Contrast is some measure of the difference between the brightness levels of the bars and surround. Although many such measures are possible, a straightforward luminance ratio is the measure generally accepted in the photo-optical community. The percent of light reflected from the test target elements determines the resultant luminance ratio, e.g., 33% reflectance of the bars and 7% reflectance of surround on a CORN test target. For these effective reflectivities, the luminance ratio is 33/7 or a 4.7:1 contrast. The solar altitude is of prime importance in determining the illumination on the test target. Local haze conditions, test target reflectivity, its angular reflection dependence, and spectral composition can alter the apparent test target contrast. Under any operant condition, however, the actual luminance ratio does define the test target contrasts.

In the case of test targets which transmit light, such as those used in collimators, the same principles apply. Luminance ratio in these circumstances is referred to as test target contrast (TTC).* TTC is determined either by a direct ratio of the bar and surround transmission measurements or by taking the antilog of the measured density difference. For example, if the bars measure 0.3 in density (50% transmission) and the surround measures 0.6 in density (25% transmission), the contrast is 2:1. This is derived as follows:

$$TTC = \frac{50\%}{25\%} = 2 \qquad \therefore TTC = 2:1$$

$$\text{also, } TTC = \text{antilog}\,(.6 - .3) = \text{antilog}\ .3 = 2 \qquad \therefore TTC = 2:1$$

Although other contrasts are possible, two contrasts are normally employed for system performance testing on the ground using collimators. These contrasts are 100:1 or greater (high contrast) and 2:1 (low contrast). The influence of contrast on resolution is discussed later in this section.

In practice, a tribar test target containing very small elements (high spatial frequency) is most difficult to fabricate with uniform contrast throughout. Luminance ratios for the smallest elements tend to decrease with increasing spatial frequency.

*It is also referred to as test object contrast (TOC). In this standard, however, the term "test target contrast" will be used.

2.2.6 Modulation

Modulation is another means for describing contrast. It is needed for analyses which are based upon transfer function and Fourier analysis techniques. Furthermore and, perhaps as important, is that modulation is a mathematical value that can be readily manipulated whereas contrast cannot. These concepts originated in electronic communication signal analysis and have been incorporated and modified for use in the photo-optical field when studying system behavior. One of the most familiar applications makes use of the threshold modulation (TM) curve for photographic emulsions, along with lens modulation transfer function (MTF) data, to determine the expected resolving power of a lens-film system.

The concept of modulation and its relationship to photo-optical systems can be explained by analogy to the communication field. In a linear communications channel, there are four basic components:

A. Signal.

B. Transmitter.

C. Medium.

D. Receiver

The transmitter sends a signal. The medium transfers the signal and quite frequently interferes with the purity of the signal by adding "noise." The receiver captures the combined signal and noise, perhaps introducing more noise, and attempts to reconstruct only the signal. A measure of the efficiency with which the transmitted signal is transferred and received is generically referred to as the transfer function.

The signal being transmitted has a strength or amplitude characteristic. The ratio of this signal strength to the average level is called "modulation." In order to have modulation, two components (a pattern and its surround) are necessary. If the pattern is weak with reference to the surround, then the signal is weak and is said to have low modulation. Often the signal can be adjusted to increase the pattern/surround ratio and so modulation increases. In effect, when signal modulation (or the pattern/surround ratio) changes, it influences the extent to which patterns are detected and recognized. The higher the modulation, the easier it is to isolate the pattern from the surround and accompanying noise, and the smaller the signal dimension that can be detected.

Photography has the same four basic components. When determining GRD, the luminance ratio of the tribar test target becomes the signal. This signal is transmitted via an optical system to a film receiver. There are many factors which affect the signal quality of this communication system, as there are with all communication systems. If the transmitter, transfer medium, and receiver characteristics are held constant, then the signal quality (modulation) is of primary concern. The tribar test target signals used in resolving power analyses can vary in signal output from 0 to 1.0 modulation based upon the bar/surround proportioning or, more directly, the contrast of the test target elements. The higher the contrast, the greater will be the effective test target element modulation. Modulation (M) can be calculated in several ways:

$$M = \frac{\frac{T\ max}{T\ min} - 1}{\frac{T\ max}{T\ min} + 1}$$

$$M = \frac{C - 1}{C + 1}$$

$$M = \frac{T\ max - T\ min}{T\ max + T\ min}$$

where:

$$C = \text{contrast}\left(\frac{T\ max}{T\ min}\right)$$

T = transmission (percent)

or, in terms of density (D):

$$M = \frac{\text{antilog}\ (D_{max} - D_{min}) - 1}{\text{antilog}\ (D_{max} - D_{min}) + 1} = \frac{(\text{antilog}\ \Delta D) - 1}{(\text{antilog}\ \Delta D) + 1}$$

A plot of signal modulation $\frac{C-1}{C+1}$ versus log TTC is shown by the dashed line in Figure 2-8. The curve shows that signal modulation increases very rapidly (starting at low values) and gradually approaches maximum modulation near a log test target contrast of 2.0 (100:1 TTC). Some specific values are shown in Table 2-1.

Figure 2-8 shows that the maximum signal, for all practical purposes, is obtained at a 100:1 TTC, and that a nearly maximum signal is obtained at a 10:1 TTC. Simply stated, the change in signal modulation from 10:1 to 100:1 test target contrast is so slight that one would expect little difference in signal recognition between these test target contrast/modulation values. Below 10:1 test target contrast, modulation decreases very rapidly, and therefore the signal becomes weaker in reference to the surround. With weaker signals, detection and recognition are also reduced because of their direct relationship to modulation.

Signal recognition, or signal detection, is described in terms of spatial frequency, or the number of bar-width pairs per unit distance which can be observed. In measuring the resolving power of a photographic system, it is evident that the peak resolving power decreases as the test target contrast decreases. It is also apparent that there is some maximum resolving power which the system is capable

TEST TARGET MODULATION VERSUS
LOG TEST TARGET CONTRAST

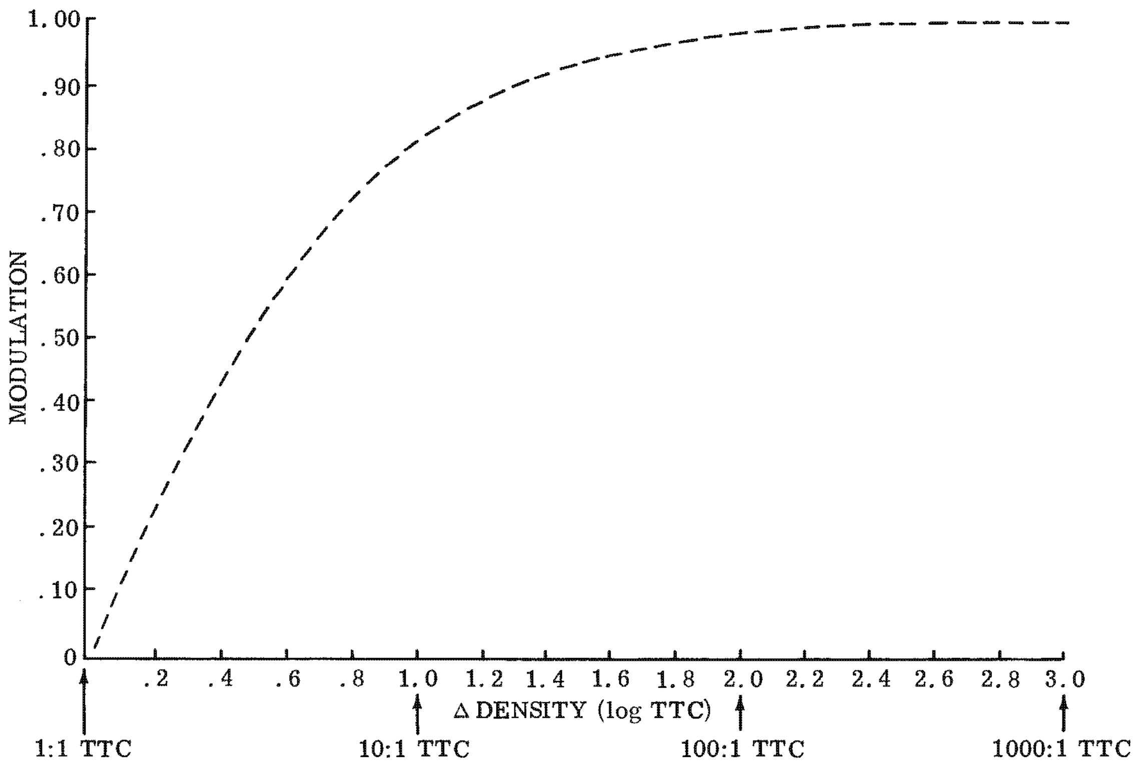


FIGURE 2-8

TABLE 2-1

RELATIONSHIP BETWEEN TEST TARGET CONTRAST AND MODULATION

Test Target Contrast	Modulation	Test Target Contrast	Modulation
1:1	0	5:1	.666
1.1:1	.048	10:1	.818
1.5:1	.200	100:1	.980
2:1	.333	1000:1	.999

of recording. This characteristic relationship is, in fact, a threshold modulation response of a film. The threshold modulation curve is defined in the Glossary, page D-8. The actual test target contrast required to produce maximum resolving power is very dependent on the system under test.

2.3 FACTORS AFFECTING SYSTEM RESOLVING POWER

When attempting to measure the resolving power of a camera system, an understanding of the factors that influence the values obtained is essential, because the same factors ultimately influence the ground resolution the system will produce. The major factors that influence the measured resolving power of a camera system are:

A. Optics.

B. Image motion (uncompensated).

C. Film.

D. Exposure.

E. Focus.

F. Scene contrast.

G. Scene content.

While it is not the purpose of this discussion to evaluate each of these factors in-depth, a few words on how they influence resolving power are appropriate. The discussion is intentionally conceptual, since the properties of various systems differ.

2.3.1 Optics

The optical system will alter the image quality in several ways. The lens imparts a finite limit upon the spatial frequency that will pass. This is known as the diffraction limit. Also, it can have physical flaws which cause a uniform loss in image contrast and hence resolution. Aberrations will further degrade the image quality in various ways. The combined result is the optical spread function which affects both the resolution and contrast of the image. The amount of contrast lost is a function of an object size; the smaller the object, the greater the loss. However, in the terms of this discussion, the effect of the optical system is to place an upper limit on the resolving power that can be achieved.

2.3.2 Image Motion

All reconnaissance cameras have the problem of compensating for image motion. Image motion, in its simplest sense, is due to the motion of the vehicle, the earth, and the camera components. The forward velocity of the vehicle produces what is known as in-track image motion. The rotation of the earth under the vehicle produces elements of both in-track and cross-track image motion and lastly the rotation of the optics (such as in a panoramic camera) can produce a significant cross-track image velocity, depending on the focal length of the camera and the altitude above the terrain. How significant any of these image motion contributors are depends on numerous factors, e.g., camera type (strip, frame, pan, etc.), height above the earth, and focal length of the camera.

Compensation for the vehicle's forward velocity is achieved in two basic ways. With a strip camera, the in-track image velocity is compensated for by moving the film during the exposure time. With a panoramic camera, the in-track motion component can be compensated for by skewing or rotating the exposure slit during photography to minimize the effect of in-track altitude and hence velocity differences.

Cross-track image motion can also be compensated for, to some extent. With a panoramic camera, cross-track motion can be compensated for by moving the film in the cross-track direction. With a strip camera, cross-track image motion is, strictly speaking, not compensated for but minimized by crabbing the mirror to align the image velocity vector with the film velocity vector.

Even the most complicated camera system cannot completely compensate for image motion. At best, image motion can only be compensated for on a line down the center of the major and minor axis of the format. This is due primarily to the fact that slant range is varying over the entire format, and only one specific set of velocity conditions can be compensated for. These geometrical uncompensated errors are called "fixed known errors."

The photographic effect of uncompensated image motion is called "smear". After the camera designer has done the best he can to compensate for image motion errors, he still is faced, in a performance sense, with two residual degrading smear-related factors. First are the remaining fixed known uncompensated errors discussed above. These errors can be precisely known. The second set of errors relates to how well the camera builder has been able to electromechanically implement the image motion compensation(s) required. This latter case produces image velocity errors which can be both known and unknown and linear or non-linear.

The effect of uncompensated image motion is to degrade the photographic image quality. This degradation has two distinct effects on the recorded image. The first is a physical distortion of the geometric fidelity, and the second is the loss of resolution produced due to the loss of contrast from image spreading.

Both fixed and random image motions result from the image going too fast or too slow relative to the film. They can combine to produce better or worse resolution depending on whether their relationship is additive or subtractive. For example, a fixed known smear error of +5 microns can combine with a random disturbance of -5 microns to produce no smear. Unfortunately, however, a +5 micron fixed error can combine with a random error of +5 microns to produce 10 microns of smear. The important point is that smear reduces resolution, and it usually does this in a random way. This is one of the factors causing the resolving power of a camera to be statistical in nature.

2.3.3 Film

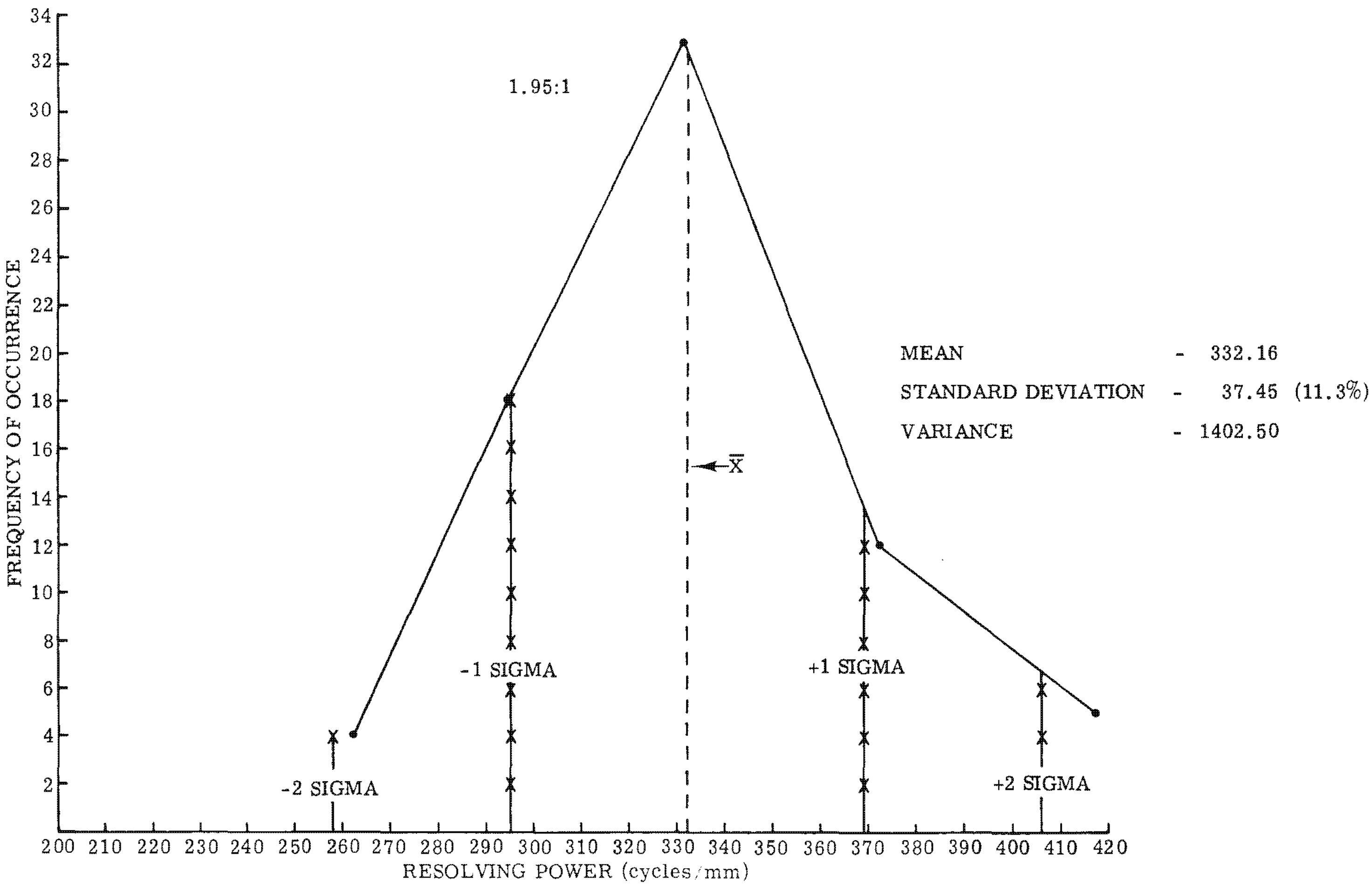
The film is a major contributor to the resolving power properties of a camera system. The lens establishes an upper limit of resolution and, if there are no other degrading factors, will do that consistently. However, the film has statistical resolving power properties. Perhaps the greatest fallacy in resolving power testing and reporting procedures is the specification of a single value to characterize the resolving power of a film at a given target contrast, exposure, and processing. In reality, the value reported is only an indication of the central tendency of the resolving power data. Actual values obtained under identical testing procedures can vary from the average resolving power with no change in any of the test parameters or basic film characteristics. An example of this is shown in Figure 2-9, which shows data obtained from a 1.95:1 luminance ratio resolving power test of Film Type 3414 under replicate test conditions. The plot of 72 data points as a function of their frequency of occurrence at a given resolution level exhibits a reasonably normal distribution. It is readily seen that quoting only a single value for the resolution of the film is highly misleading since a significant portion of the time the film will produce higher and lower resolving power values. The quoting of a single value for system resolution (without proper qualification) assumes a single value of film resolving power. Therefore, it is clear that the resolving power values obtained with a given system, even if performing consistently, will fluctuate due to the statistical nature of the granularity of the photographic material.

This noise source in system resolving power is influenced by the type of chemical processing which the original negative receives to develop the latent image. Changes in processing parameters (chemistry, time, temperature, agitation) induce variation in both sensitometric and grain structure properties. These, in turn, result in changes in either average resolution level, resolution variability, or both. For example, a change from spray to viscous developer application or from "dual gamma" to "modified dual gamma" configuration causes a change in microsensitometric edge effects; microscopically, the rendition of imagery at the resolution threshold is modified. In summary, the film type and particular processing it receives are contributive factors to ultimate system resolving power.

2.3.4 Exposure

Film resolving power is a function of exposure; and unless the tribar target is exposed properly, peak resolution will not be achieved. In practice, although exposure levels are selected to encompass the linear portion of the sensitometric response curve of the film and chemistry being used, highlight and shadow detail often encroach upon the upper and lower portion of the curve. Since a ground scene has a significant dynamic luminance range, resolution is commensurately distributed about its peak, even though for example, an acquired test target may be at its own optimum exposure level.

RESOLUTION TEST DISTRIBUTION



NOTE: This test was made on 3414 Film Type which was processed dual gamma in a Yardleigh Processor.

FIGURE 2-9

TOP SECRET-HEXAGON / GAMBIT
Approved for Release: 2018/07/31 C05106617

2.3.5 Focus

A major system influence on resolution is the ability to keep the film in the plane of best focus of the lens. If the camera/film combination is not at optimum focus, the resolution rendered will be less than its potential peak value. Even when a camera is properly focused, there can be areas of defocus on the photographic format. Under operational conditions, there can be some fluctuation in absolute film position, along with the possibility of a non-flat optical field from which the film physically departs from best focus in some places. As a result, focus performance varies across the frame format during photographic operations. The extent to which resolution levels will be affected by this variability depends on the camera/film characteristic response and how accurately focus is controlled.

2.3.6 Scene Contrast

Even with a system operating at its peak, the resolving power (or resolution) produced will be a function of contrast. This fact cannot be overstressed. Both the measurement of resolving power and the information content of the photography are affected by contrast. During photographic operations, even a controlled ground target of fixed reflectivity under constant daylight illumination will not present the same contrast to the camera under replicate acquisition conditions. Scene contrast above the atmosphere is very sensitive to weather conditions and local atmospheric haze, both of which change frequently and often dramatically. Even within a single frame or within frames of a given operation, the variations in solar azimuth, solar elevation, and target acquisition angle introduce changes in ground contrast for a given controlled resolution test target. This situation persists because targets which reflect uniformly in all directions cannot yet be constructed.

The situation is even more variable with real intelligence targets, as they are a composite array of luminance ratios. Thus, a gamut of contrasts of interest on the ground, further altered by variations in local atmospheric conditions, results in some distribution of image quality. For a well-operating reconnaissance camera system, weather-induced photographic image degradations cause by far the most significant loss to image quality and, hence, intelligence value.

2.3.7 Scene Content

As a final consideration, resolution achieved by the camera/film system is dependent upon many minor factors which might be treated unilaterally as configuration related. An example of configuration is the shape of the tribar test target element. A change in length, width, or space between bars would clearly alter threshold discrimination and thus modify the resolution. In practice, because tribar test targets are standardized, this is not a source of error. However, real intelligence targets are structured with innumerable shapes, sizes, and background textures which cause variations in resolution. Other factors which might be included as scene configuration considerations are degree of obliquity, shadow length and orientation, unusual spectral signatures, and linear extension phenomena, i.e., railroad rails, telephone wires, highway markings, and the like on the ground. Different degrees of snow cover also influence the effective target configuration by obscuring, amplifying, and altering various components of the scene.

All of the above causes of resolution variability combine to produce a final photographic product that can be characterized by an average resolution level about which measured samples will fluctuate according to some distribution. A sufficient number of test targets (such as tribars) acquired during ground testing will provide a measure of central tendency and variability. This performance level indicator may have some relationship to the level of detail visible within the intelligence target acquisitions. Variability in image quality and information content will be considerably greater with operational imagery because of the various scene content factors discussed above.

2.4 GROUND RESOLUTION AND GROUND RESOLVED DISTANCE

System resolution alone does not reveal the potential information content of the system's photography. For example, a "100-line system" will achieve better ground resolution at 50 nautical miles than it will at 300 nautical miles. All else being equal, the higher altitude condition will result in six times poorer ground resolved distance (GRD) than the lower altitude condition. More directly, for a system at 300 nautical miles to produce the same GRD as the 100-line system at 50 nautical miles, it would have to produce 600 lines/mm. The fundamental relationship between system resolving power (in lines/mm) and GRD (usually expressed in feet or inches) is simply that of scale.

Deployment of a mobile standard tribar test target by a CORN crew permits direct measure of GRD at that point within the frame at which it was imaged. Microscopic examination of the original negative at that point provides an immediate and literal assessment of the ground resolved distance. Such an isolated sample, subject to the variability described above, will not necessarily represent the typical performance level.

Adjacent deployment of calibrated photometric patches (of sufficiently large size for the photographic scale involved) provides a means for inferring the contrast of the tribar test target image. This provides information essential to the normalization (adjustment) of GRD to some accepted fixed contrast level, thereby removing test target contrast changes from the system performance indication. Re-expression of GRD in terms of system resolving power is accomplished by accounting for all the factors which influence the scale of the photography at that point in the format.

Factors which influence scale are camera focal length, vehicle altitude, obliquity, geometric perspective, and the earth's curvature. The latter two factors are often disregarded, but this will lead to inaccurate GRD values in off-nadir photography. In any event, even for the hypothetical situation of constant resolution over the entire format, GRD will vary in proportion to scale.

Estimations of ground resolved distance must be treated in the same statistical fashion as system resolution, since they are proprotional equivalents. This implies that the achievement of a desired GRD at a spatial/temporal designated location in mission photography is a probabilistic event.

Even if system resolving power and ground resolved distance are properly characterized for a given mission product, the translation of these quantitative terms into the more qualitative and useful terms of information content, e. g. , photographic interpretability or intelligence value, is not straightforward.

The specific factors that influence the GRD of a given photograph or area within a photograph are complex. This subject was treated in-depth in a previous report.[1] In summary, that report illustrated why CORN target derived GRD values can be unrepresentative of real intelligence target achieved ground resolution.

The following basic factors affect GRD:

A. Geometric relationships.

B. Atmospheric haze.

C. Illumination geometry and target type.

D. Camera resolving power.

Camera resolving power has already been discussed in paragraph 2. 3; the effects of the other variables are summarized below.

2.4.1 Geometric Relationships

The following three factors are key in the scale conversion of lines/mm to GRD:

A. The earth model assumed (i. e. , flat, round, or oblate).

B. Perspective.

C. Vehicle pitch.

There should be little argument about the desirability to use round earth geometry in preference to flat earth geometry, particularly when computing GRDs at high scan (roll) angles. A comparison of the ratio of slant ranges and scan angle is shown graphically in Figure 2-10.

The second important factor is the perspective, that is, the angle at which the object is viewed by the camera. Because photographic interpretation involves vertical objects as well as horizontal objects, it is important to understand how they relate to horizontal dimensions in terms of GRD. Vertical objects are considered to be normal to the tangent plane at the intersection of the line of sight ray (optical axis) and the curved earth. Another GRD considered is the projection of the pitch dimension of the lens resolution (1/RX or 1/RY) onto the plane that is normal to the optical axis at the particular slant range

[1] "Considerations Concerning Factors Affecting Ground Resolved Distance," PFA Technical Report No. 2, TCS 363501-73, February 1973.

COMPARISON OF THE SLANT RANGE FOR ROUND EARTH GEOMETRY VERSUS FLAT EARTH GEOMETRY AS A FUNCTION OF SCAN ANGLE
(90.8 NM)

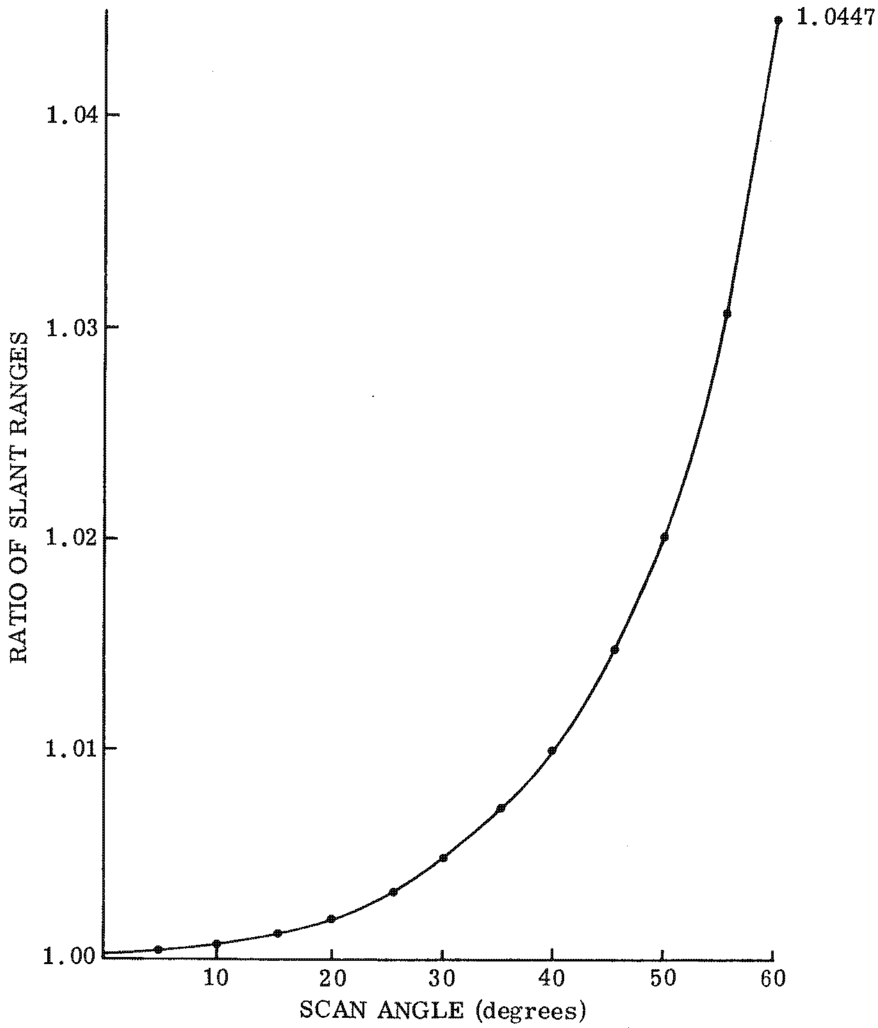


FIGURE 2-10

for the scan angle being considered. Figure 2-11 on page 2-20 is an illustration of the various GRDs where the vehicle is traveling normal to the plane of the paper. The in-track GRD is also normal to the plane of illustration. Calculations are made to solve these various GRDs. The entire set of values is then normalized to 1.0 at zero scan by dividing the GRD by 2.407 feet, which is the geometric mean of the in-track and cross-track directions for zero scan.

To illustrate the effect of scan angle on ground resolved distance based on geometry alone, a typical set of conditions was assumed for the 1200 series. These conditions are also generally applicable to the 4300 series. They are:

h = 90.8 nautical miles, altitude
R = 3434.1 nautical miles, radius of the earth
f = 60 inches, focal length
θ = 10°, stereo offset angle
α = variable, scan angle
RX = 154 lines/mm, resolution, in-track direction
RY = 154 lines/mm, resolution, cross-track direction

Figure 2-12 shows the relative GRD in the cross-track and in-track directions for dimensions in the plane of the surface of the earth. As expected, the in-track GRD is better than the cross-track GRD by a factor of about 2:1 at a scan angle of 60 degrees. This factor of two difference is the result of look angle geometry only, because the resolution at the film plane in this calculation is the same for both directions (154 lines/mm). Another interesting fact is that the GRD in the cross-track direction is about 4.5 times poorer at a scan angle of 60 than it is at 0 degrees scan. Figure 2-12 also gives the geometric mean GRD of the in-track and cross-track directions.

RELATIVE GROUND RESOLVED DISTANCE VERSUS SCAN ANGLE OF A HORIZONTAL OBJECT (90.8 NM)

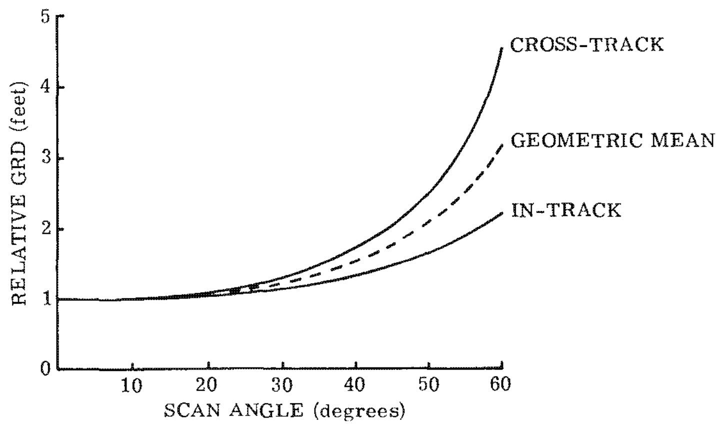
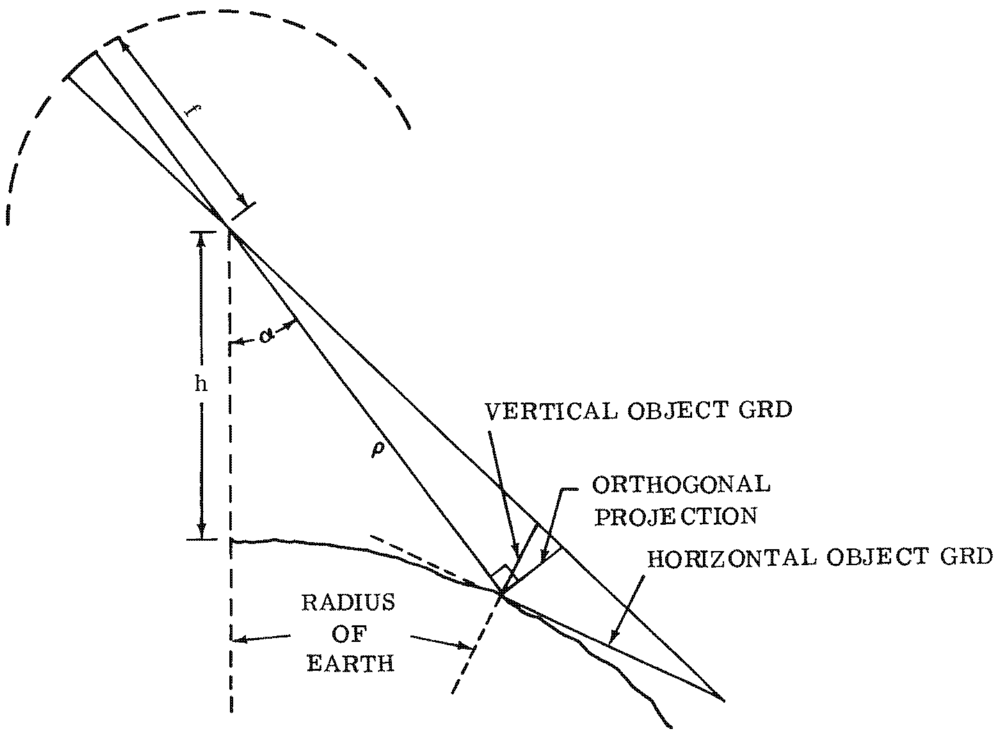


FIGURE 2-12

BASIC GEOMETRIC RELATIONSHIPS



f = CAMERA FOCAL LENGTH
h = VEHICLE ALTITUDE
ρ = SLANT RANGE TO TARGET
α = SCAN ANGLE

FIGURE 2-11

The projection of the pitch dimension of the lens resolution (1/RX or 1/RY) onto the plane that is normal to the optical axis at the particular slant range in question is a GRD that has little direct application. The projection is presented in Figure 2-11 for reference only. Further projection of this GRD onto the horizontal plane of the earth provides the in-track and cross-track GRDs discussed above. Figure 2-13 gives the projected GRD as a function of scan angle. This agrees closely with the in-track GRD given in Figure 2-11.

GRD BASED UPON PROJECTION OF THE PITCH DIMENSION OF LENS RESOLUTION ONTO PLANE NORMAL TO LENS AXIS AT THE PARTICULAR SLANT RANGE (90.8 NM)

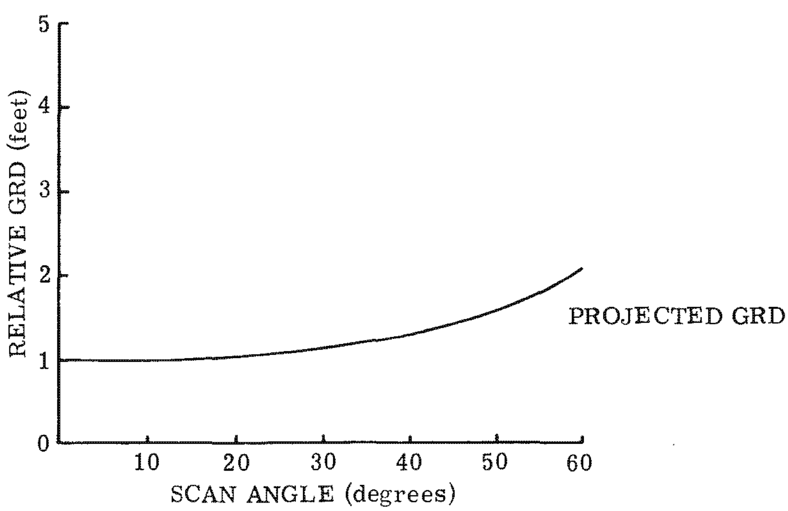


FIGURE 2-13

For the definition of the GRD of vertical objects, see Figure 2-14. The in-track vertical GRD (VX) might relate to window widths in a building, for example, whereas the cross-track GRD (VY) might relate to window heights. Figure 2-15 gives the relationship between GRDs (VX and VY) at various scan angles. As one would expect, the vertical surfaces become better resolved as the scan angle increases. The GRD then becomes poorer when the slant range becomes the predominant factor. It is interesting to note that the smallest GRD is obtained for VX and VY at scan (roll) angles of about 30 and 45 degrees, respectively.

GROUND RESOLVED DISTANCES OF VERTICAL AND HORIZONTAL OBJECTS

VX = IN-TRACK GRD OF VERTICAL OBJECTS
VY = CROSS-TRACK GRD OF VERTICAL OBJECTS
X = IN-TRACK GRD OF HORIZONTAL OBJECTS
Y = CROSS-TRACK GRD OF HORIZONTAL OBJECTS

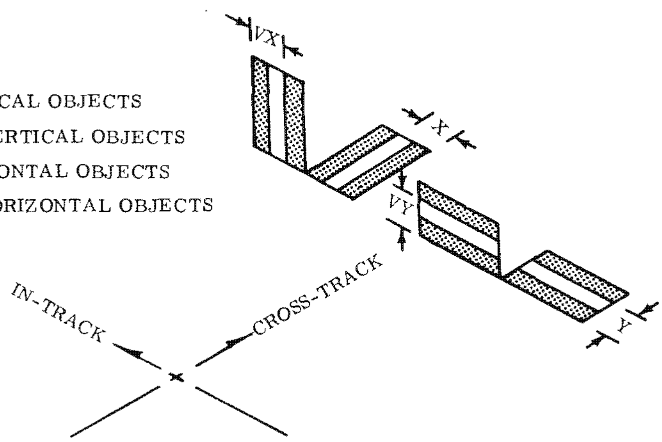


FIGURE 2-14

IN-TRACK AND CROSS-TRACK GRD FOR VERTICAL OBJECTS
AT VARIOUS SCAN ANGLES
(90.8 NM)

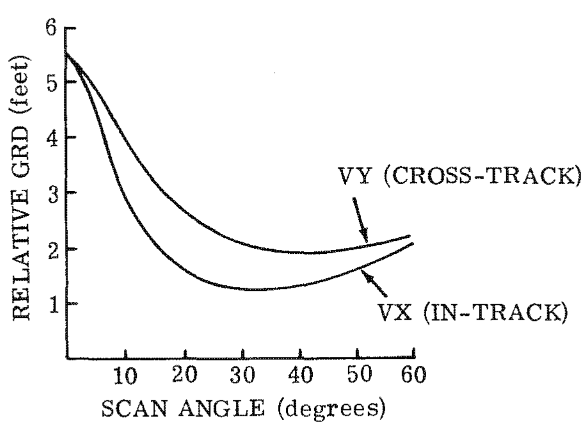


FIGURE 2-15

The graphs show that different mathematical relationships are required to compute the GRD of an object, depending on both orientation and camera parameters of the object. Knowledge of the scale alone is not sufficient to accurately estimate in-track and cross-track GRDs of various targets under various conditions. The most common practice is to refer to the GRD of objects on a horizontal plane, e.g., CORN tribars; for this case, the proper equations to be used are:

$$\text{In-track } GRD_x = GRDX_o \ (\sec\theta)^{1.15}$$

$$\text{Cross-track } GRD_y = GRDY_o \ (\sec\phi)^{2.12}$$

where:

$GRDX_o$ and $GRDY_o$ correspond to the GRD at 0° scan.

2.4.2 Atmospheric Haze

The effect of haze is to reduce the ground resolution by reducing target contrast. The effect of haze conditions on a horizontal target in daylight depends on a number of factors, the most important of which are the haze level and the target contrast on the ground.

Figure 2-16 illustrates the relative loss in GRD for two haze conditions and two test target contrasts. The 22.6/7.5% test target reflectance ratio corresponds to a high contrast intelligence target, while the 20/10% reflectance target characterizes an average intelligence target. Using this data, estimates of the resolution loss that will occur under the various conditions can be made. Table 2-2 illustrates the approximate loss in resolution that will occur under the haze/target contrast conditions noted. This table also clearly shows the effect that target contrast and haze level have on the resolution achieved. These losses are a function of solar altitude and become more severe as solar altitude decreases.

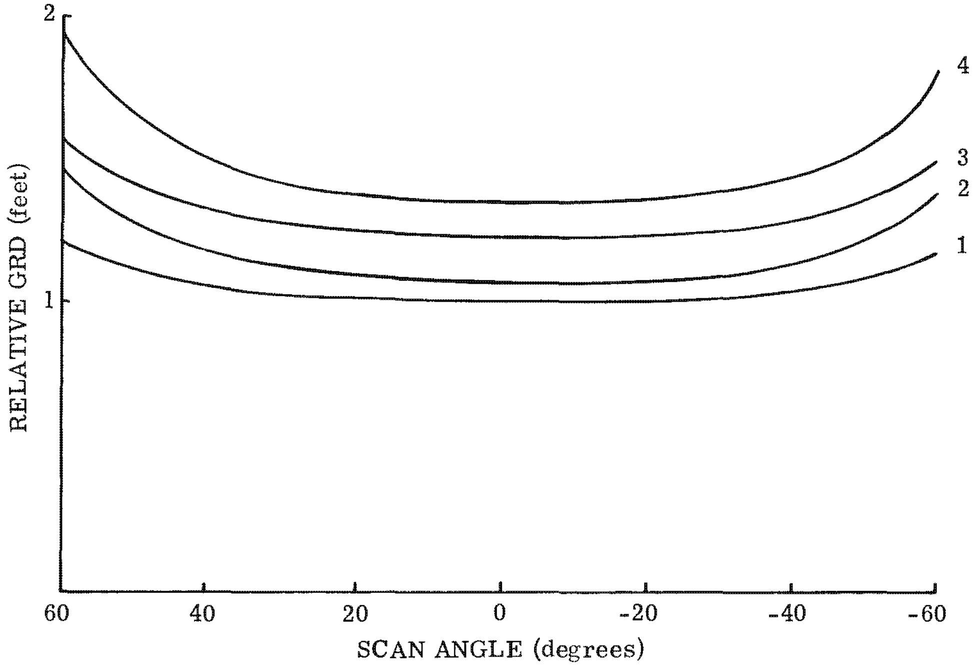
TABLE 2-2

PERCENT LOSS IN RESOLUTION DUE TO HAZE AND TARGET CONTRAST CONDITIONS AT TWO SOLAR ALTITUDES

Haze Condition	Solar Altitude (degrees)	Target Contrast: High (26.6/7.5%)	Target Contrast: Average (20/10%)
Average	40	0	18
Heavy	40	7	25
Average	10	12	30
Heavy	10	30	40

NOTES: 1. These values were computed for 1200 series camera systems but are close approximations for 4300 series systems as well.
2. The losses are normalized to the high contrast/average haze condition at 40° solar altitude. The table is not intended to indicate that there is no loss under this condition.

RELATIVE EFFECT ON GRD DUE TO HAZE ONLY



Condition	T550	Target Reflectance (Rmax/Rmin %)	Resolving Power (cycles/mm)
1	.697	26.6/7.5	186
2	.584	26.6/7.5	173
3	.697	20/10	153
4	.584	20/10	140

NOTES:
1. The T550 means transmissions at 550NM.
2. The values under the T550 column mean: .697 is equal to average haze, and that .584 is equal to heavy haze.
3. All curves are normalized to Condition 1 at nadir.
4. Solar altitude is 40 degrees.

FIGURE 2-16

SCENE CONTRAST DATA FOR URBAN/INDUSTRIAL SCENES
FOR 1200 AND 4300 SERIES MISSIONS

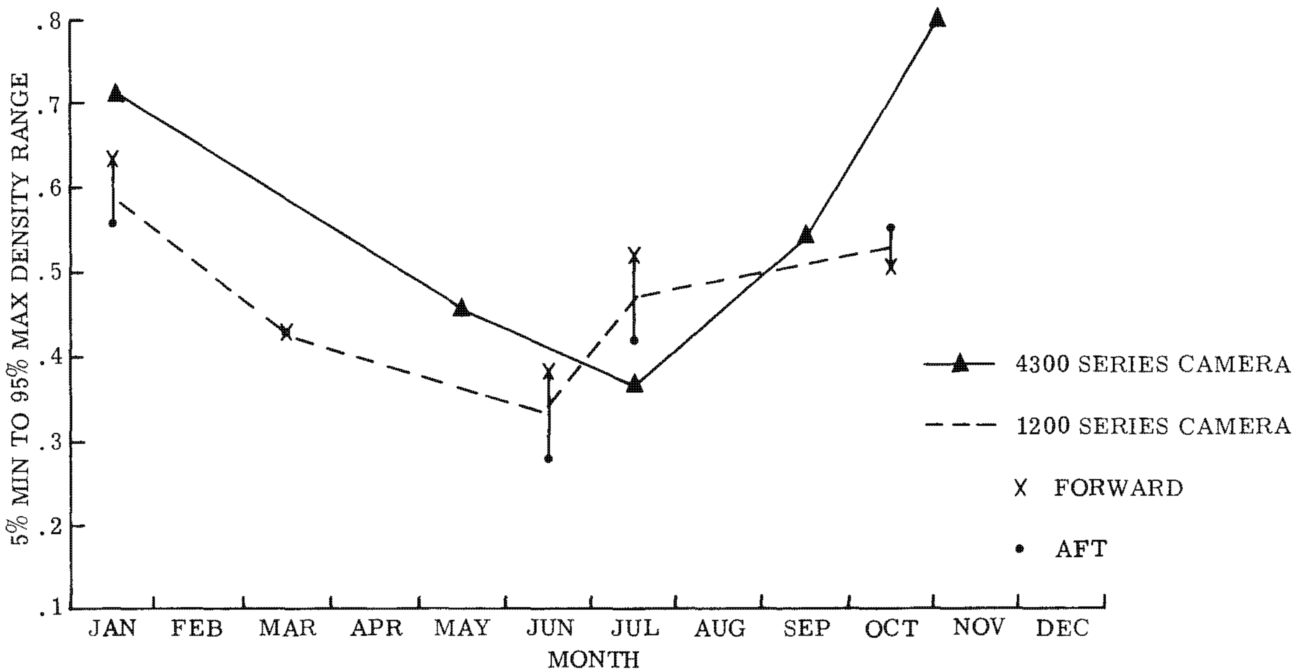


FIGURE 2-17

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Another aspect of the haze effects that must be considered is time of year. Data on haze levels versus time of year can be inferred by evaluating the contrast (5% to 95% maximum brightness) of denied area targets for missions at different times of year. Figure 2-17 illustrates this data for recent 1200 and 4300 series missions. This figure readily shows the impact of haze levels during the year and indicates that summertime missions will be the most adversely affected by lowered contrast.

2.4.3 Target Type and Illumination

There are numerous combinations of camera/target/sun (CATS) angle and target illumination that will cause variations in the amount of energy at the image plane. Even if the spectral reflectance of the target is identical under all conditions of illumination, it would not be surprising to find that the effective contrast at the image plane differs in each situation. For example, a target of interest might be found in shadow, in partial shadow, or the target could be a vertical object that is front-lighted or back-lighted. It is the purpose of this discussion to give the reader insight as to how relative GRD may vary when a single test target having a maximum and minimum reflectance of 33% and 7%, respectively, is illuminated under various conditions and is acquired from various scan angles.

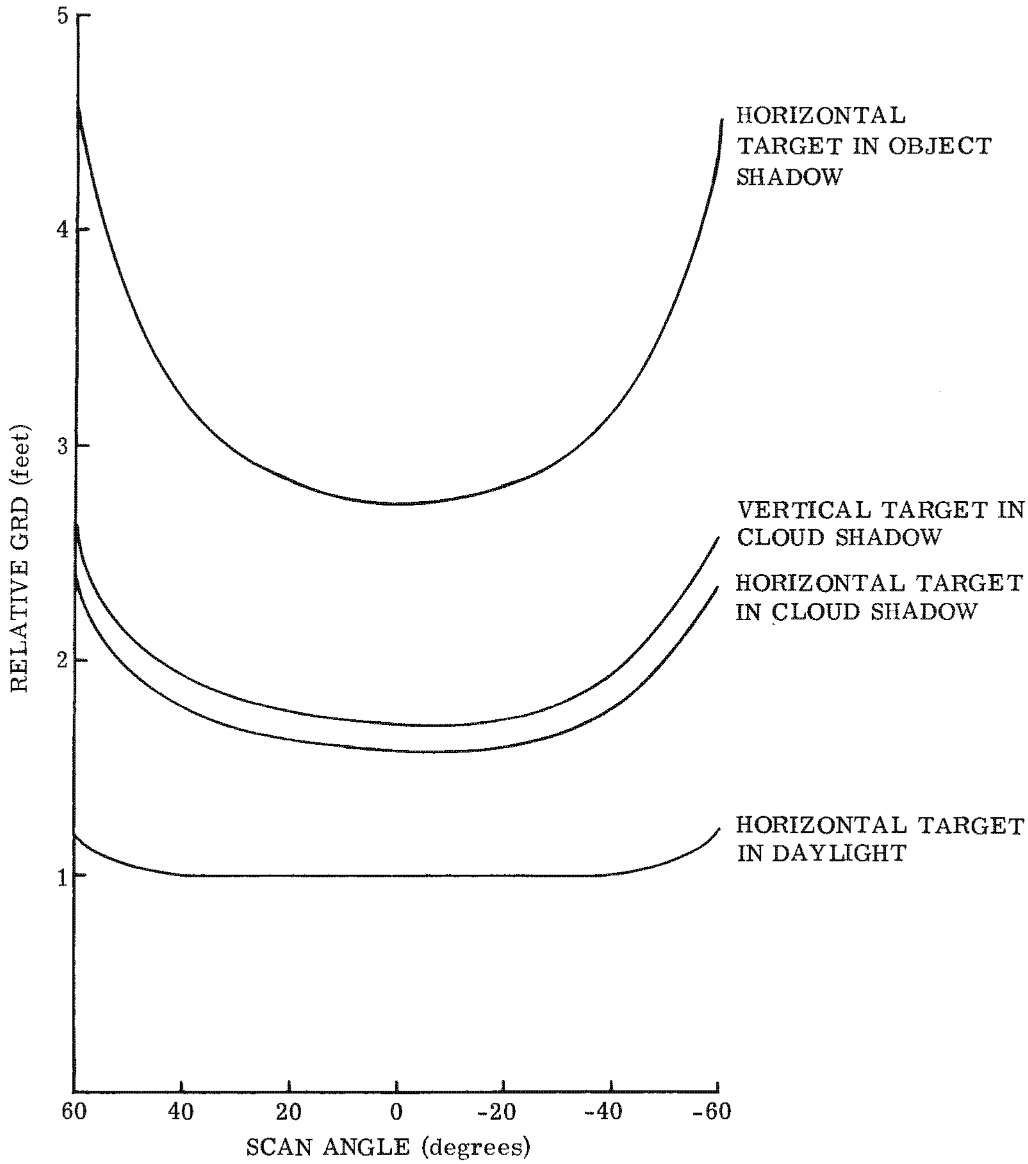
Figure 2-18 gives relative GRD as a function of scan angle for a 23 June acquisition using a Forward Camera, at 10° pitch, to photograph various targets under a variety of combinations of illumination and target orientation. The relative GRD values include only the effect of atmospheric haze, target illumination, and target orientation. Effects of slant range and other geometric considerations are excluded. The relative loss in GRD at 60 degrees scan for the horizontal daylight case in Figure 2-18 agrees favorably with the prediction of the same situation shown in Figure 2-16, even though the solar altitudes were different. In Figure 2-18, the greatest loss in relative GRD occurs when the target is either horizontal or vertical but under shadow conditions. The case for a vertical target in shadow improves, however, when acquired in December. This is the result of a lesser effect of haze combined with look angle and illumination conditions which are improved in the December acquisition. Figure 2-19 shows the results of the prediction of GRD for a 23 December acquisition. The characteristic U-shaped curve is found for every illumination and object orientation condition.

It can be concluded from these presentations that the loss in GRD attributed to illumination of objects in shadow can be as large as a factor of four or possibly larger, and that the situation of a target in cloud shadow (skylight illumination) is less severe than that of a target in local object shadow on the ground.

2.5 A PERSPECTIVE ON RESOLUTION

There are both advantages and disadvantages to resolution. The advantages are simple and

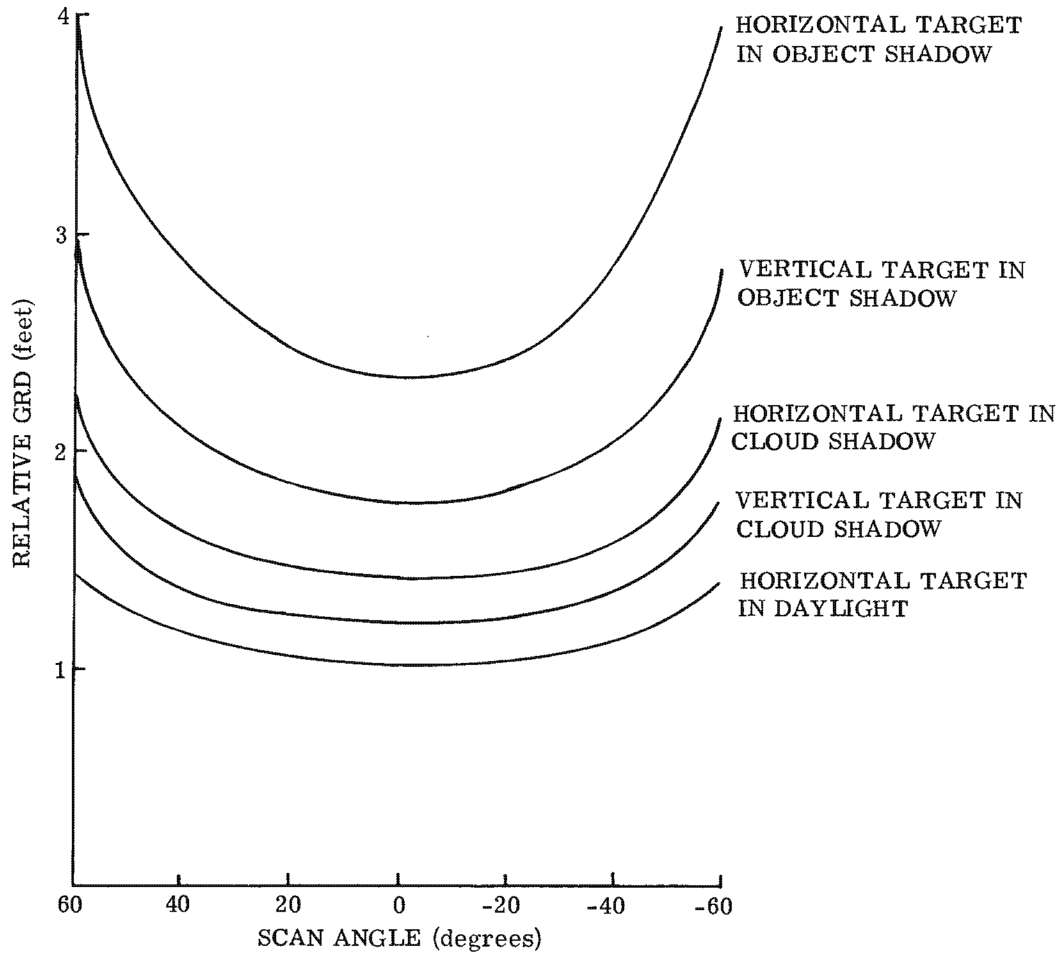
RELATIVE GRD FOR VARIOUS TYPES OF TARGET ILLUMINATION FOR SUMMER ACQUISITION



NOTE: Solar Altitude is 63 degrees.

FIGURE 2-18

RELATIVE GRD FOR VARIOUS TYPES OF TARGET
ILLUMINATION FOR WINTER ACQUISITION



NOTE: Solar Altitude is 17 degrees.

FIGURE 2-19

easy to understand. Of first importance is the fact that the concept of resolution has been employed through the years and the values obtained have a commonly understood meaning throughout the photo-optical community. Second, resolution measurements are relatively easy to make. Third, for the reconnaissance application, resolution has some meaning in that it is an indicator of something photo-interpreters are interested in, i. e., the ability to record fine detail. Last, but certainly not least, resolution measures the combined effect of all the transmitting or degrading parameters of information in the system. It can take into account the performance of the lens, the IMC error, vibration, focus, film performance, exposure, processing, viewing, and the observer. No other single system performance indicator covers as many aspects of system performance in one measurement.

However, resolution possesses several drawbacks, one of which can be the all-encompassing measuring ability discussed above. It is often impossible with a simple resolution test to pinpoint the cause(s) of degradation in system performance. Conversely, it is difficult to combine the resolution capabilities of each component of a system to obtain a valid indication of total system performance. It must be remembered that resolution is only a measure of the ability of a system or film to transmit or record a test pattern of a particular configuration, contrast, and size.

Resolution, like all single number criteria, is not a universal indication of picture quality. Image quality and resolution most noticeably conflict when using optical systems that possess unusual apertures or significant amounts of spherical aberrations. The shape of the system spread function has an important influence on the interpretability of the photographic scene. To double the resolution of a system does not necessarily mean that the information content from an intelligence point of view has been doubled. Figure 2-20 illustrates the role that spread function plays with regard to the photographic scene. In the comparison, Image A was made with a narrow spread function, while Image B was made with a spike center/wideskirted spread function. It is important to note that resolution values alone can be very misleading relative to how a picture will look to a PI. This is not a normal problem with current NRP systems.

Another way to demonstrate this is to compare another two pictures: one limited in its resolution by the lens, the second limited by the film, but both possessing the same GRD. Such a comparison is shown in Figure 2-21. It is evident that the lens-limited picture (Type 649 High Resolution Film) contains considerably more information since less grain noise is recorded than the film-limited photograph (3414 Film with near diffraction-limited lens), even though the GRDs as determined from the resolution target are equal. If one understands and accepts this point, he is ready to deal with the concept of resolution.

FIGURE 2-20

INFLUENCE OF SPREAD FUNCTION ON INTERPRETABILITY

(Photomicrographs of Two Sections)

IMAGE A

IMAGE B

NOTE: The object in Image A is more readily interpretable than that in Image B; yet Image A shows lower resolution of the test target.

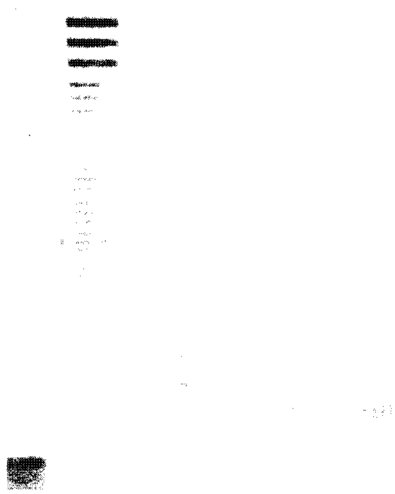
(b)(1)

Approved for Release: 2018/07/31 C05106617

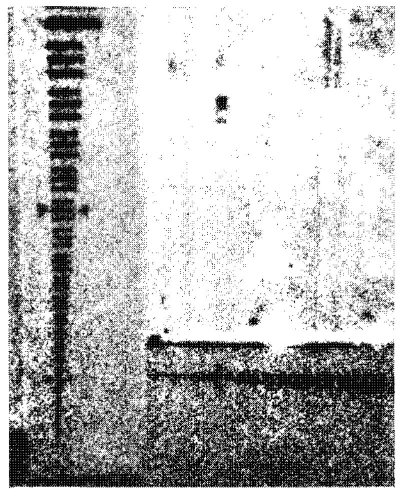
IRARS
TRIBAR RESOLUTION STANDARD

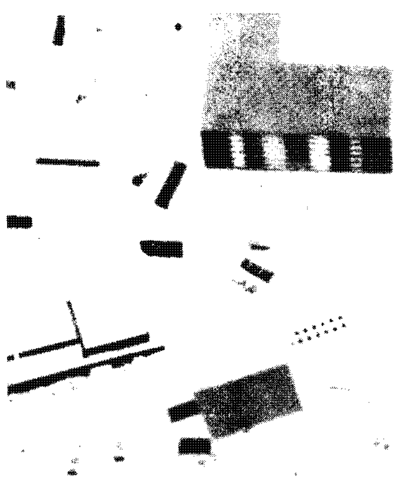
LENS-LIMITED COMPARED TO FILM-LIMITED RESOLUTION

LENS-LIMITED



FILM-LIMITED





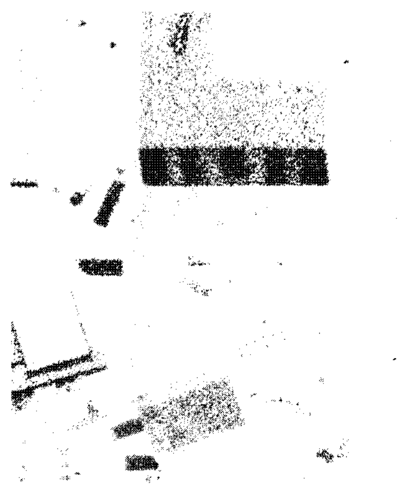


FIGURE 2-21

SECTION III

READING AND REPORTING RESOLUTION DATA

3.1 SCOPE

This section discusses the reading and reporting of resolution data for operational and laboratory film products. It prescribes the criteria to be employed in making the readings and how the data is to be reported. It also presents a standard set of terms and definitions to be used when discussing the various aspects of resolving power testing.

3.2 TERMINOLOGY

The following set of terms is hereby standardized for use in the discussion or reporting of resolving power data on all applicable National Reconnaissance Programs:

A. Test target element - a three-bar array inscribed in a square as shown in Figure 3-1.

B. Test target - an array of test target elements.

C. Group - a subset of test target elements which facilitates the identification and location of test target elements.

D. Replicate set - a series of images made under the same conditions.

E. Exposure series - a series of replicate sets obtained by giving successive increments of exposure.

F. Focus series - a series of replicate sets produced by making successive changes in the focus setting.

THREE-BAR SQUARE TARGET ELEMENT

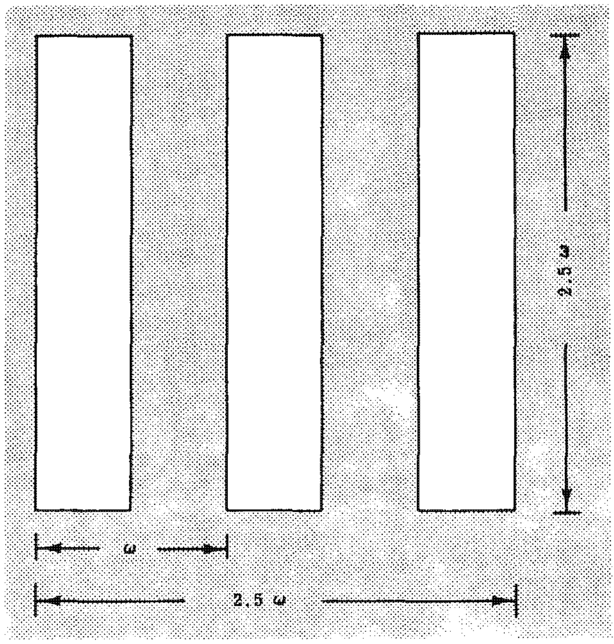


FIGURE 3-1

3.3 CRITERIA FOR RESOLUTION READING

3.3.1 Judging Specific Test Target Elements

Every observer who examines an element and decides whether or not it is resolved does, in fact, adopt some threshold for the clarity of the element. If the clarity of the element is below his threshold, he says the element is not resolved; if the clarity of the element is above his threshold, he says that the element is resolved. The following presents the criteria to be employed in judging whether or not a test target element is resolved:

A. The image of the bars in the element shall be perceived such that the number of bars could be counted with reasonable confidence even if the number were not known to be three. Otherwise, the element is judged not resolved.

B. Rounding of the corners and shortening of the bars are reasonable effects to expect in a just-resolved test target element. As a guide, the element image should show the three bars as approximately equal in length. However, the element may be judged resolved if any one bar is at least half as long as the other two and the element otherwise meets the criteria of this section.

C. For an element to be judged resolved, there must be a visual perception of density difference between the bars and their surround for the entire length of the bars even though this density difference may not be uniform for the length of the bar due to grain clumping or other artifacts.

D. A single element that is resolved but is immediately preceded and followed by elements not resolved should not be counted. See Example A in Table 3-1 and another example in Figure 3-2. However, if two or more elements are resolved after an unresolved element, then the highest resolved element should be counted. See Example B in Table 3-1.

TABLE 3-1

RESOLVING POWER EXAMPLES

Group/Elements	Examples A	Examples B
6/1	Y	Y
6/2	Y ←	Y
6/3	N	N
6/4	Y	Y
6/5	N	Y ←
6/6	N	N

NOTES: 1. The "Y" denotes resolved and the "N" denotes not resolved.
2. In the above examples, the reading to record for Example A is 6/2; for Example B, it is 6/5.

E. Spuriously resolved elements will not be counted, see paragraph 3.3.2.

F. Each element shall be judged independently, without regard for the appearance of other elements in the same picture, except as excluded under the criteria in Item "D" above.

3.3.2 Spurious Resolving Power

Spurious resolution is false or misleading and is not to be counted as resolved. This false resolution can be described as an image of an element with a phase shift. This characteristic is most often observed as a contrast reversal in the bar image, i.e., an effective interchanging of the position of bars and spaces. When the shift is present, a different number of lines than the actual number in the target element is observed, see Figure 3-3.

Examples of spurious resolution are often observed during testing. One example is caused by the lens optical transfer function when an image is out-of-focus. The observer can then look past the real resolving power limit (often up to 4-7 elements in a row which are unresolved) and then again see clearly defined bars and spaces which he may mistake for the limiting resolution. Careful observation, however, reveals these images to be spurious for they have the improper number of lines in the imaged element. This is a common example of spurious resolution; however, spurious resolution may be observed in other cases not necessarily involving an out-of-focus photo-optical system, e.g., in the case of smeared imagery, see Figure 3-4.

EXAMPLES OF SINGLE RESOLVED TEST TARGET ELEMENTS

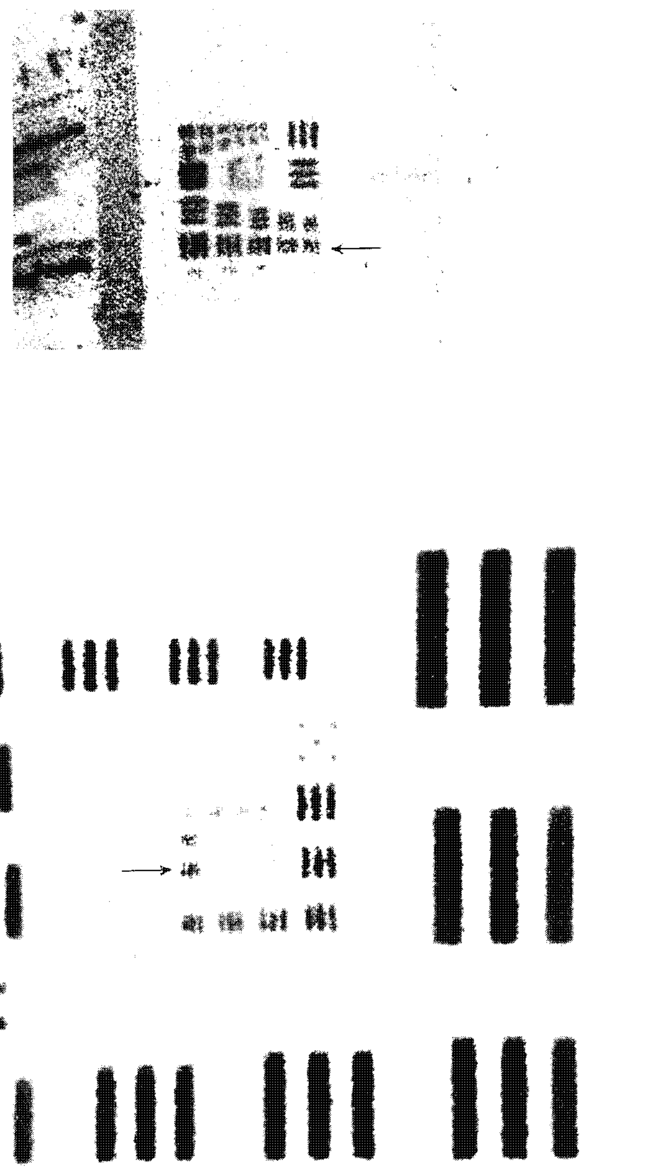
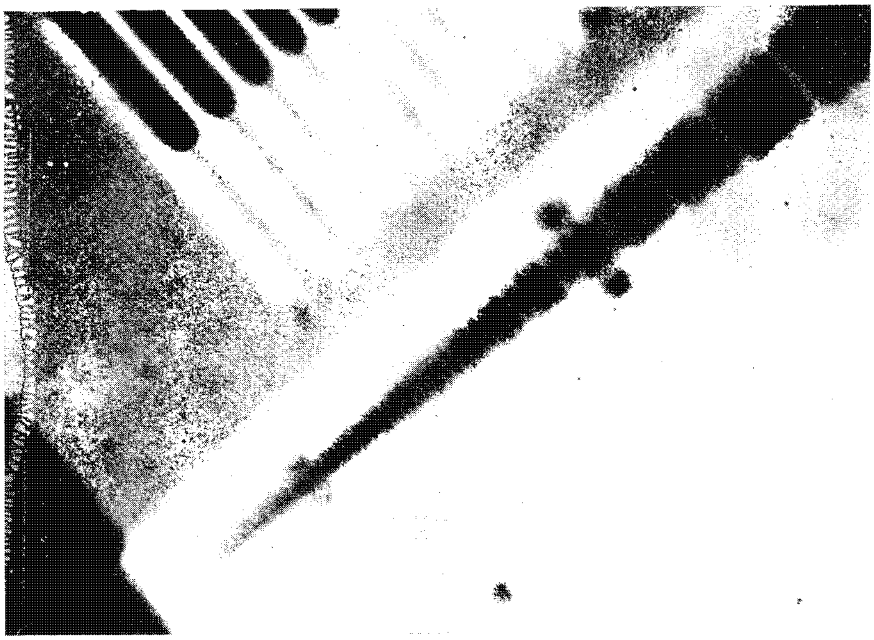


FIGURE 3-2

EXAMPLES OF SPURIOUS RESOLUTION DUE TO OPTICAL DEFOCUS



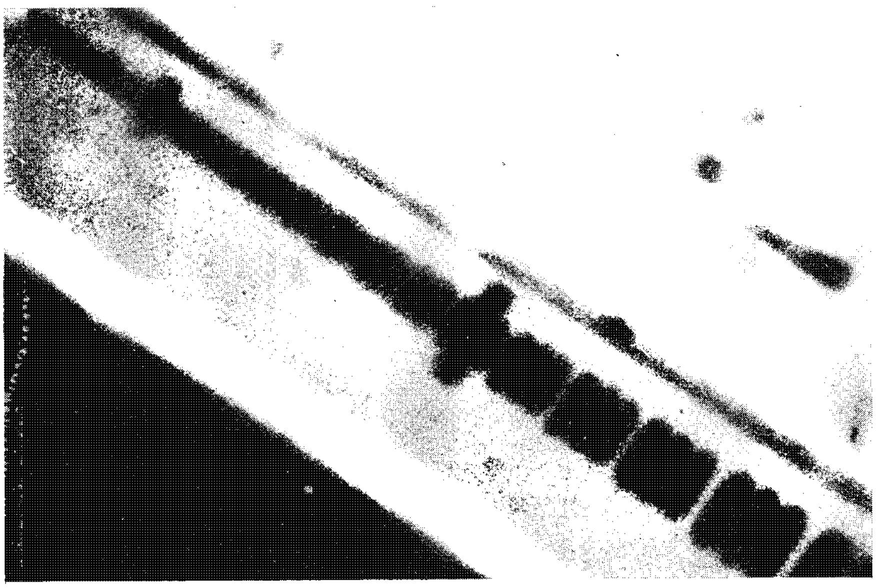
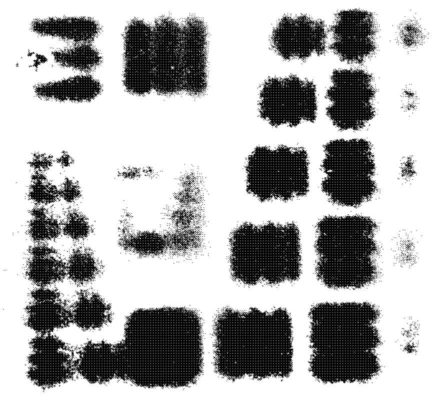


FIGURE 3-3

EXAMPLES OF SPURIOUS RESOLUTION DUE TO OPTICAL DEFOCUS (CONT'D)



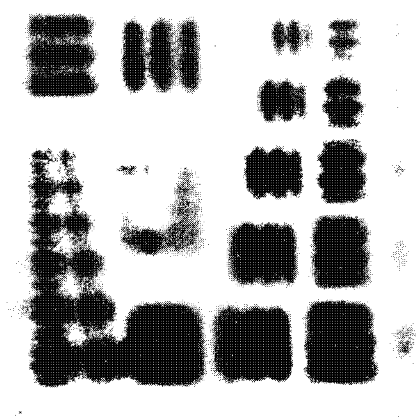


FIGURE 3-3 (CONT'D)

EXAMPLE OF SPURIOUS RESOLUTION DUE TO IMAGE MOTION

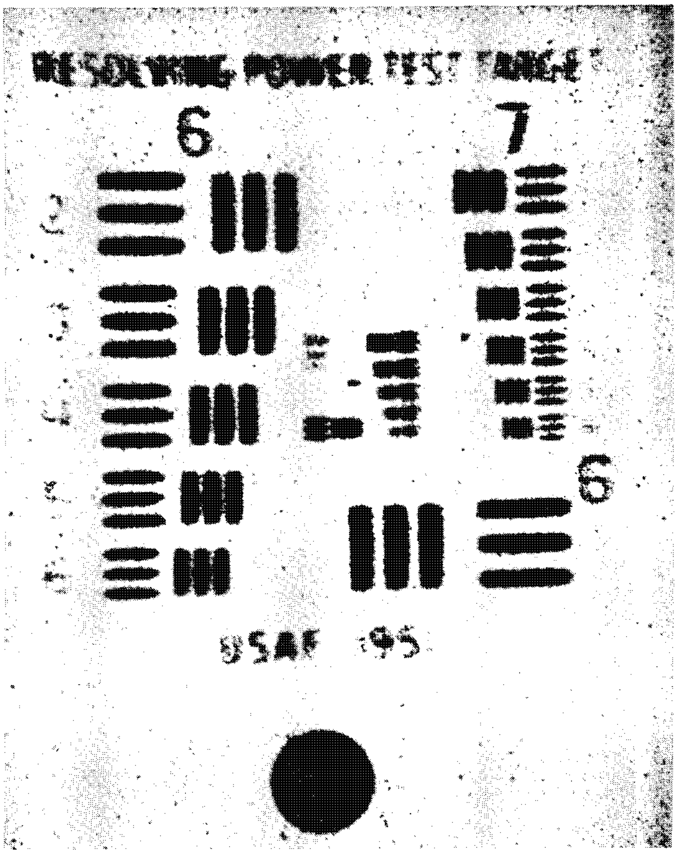


FIGURE 3-4

3.3.3 The Criterion of Reasonable Confidence

The key concept in the criteria of resolution is that of "reasonable confidence." It is intended to indicate a level of confidence that is somewhere between complete confidence and no confidence at all. The rationale for this approach is that there is important information beyond the resolution level where the tribars are read with certainty. Because this key concept is difficult to verbalize, and because it is a threshold measure, it is illustrated with pictures rather than described with words. Appendix B presents a series of resolution targets and indicates the test target element considered resolved by the IRARS-TF.

3.4 TRIBAR TARGET READERS

Resolution reader variability determines the accuracy and precision of reported resolution data. This is true no matter what kind of tribar test target is being read.

Adherence to this standard will minimize the reader variability source of error. A minimum of three readers should be used to evaluate the test target images. These readers shall use the equipment discussed in paragraph 3.5.

To the maximum extent possible, test target images should not be identified by test type but by a coded system. Readings should be recorded by target group and element, as opposed to direct cycles/mm data. This is aimed at minimizing the influence on the reader of some expected result.

Since resolution reading is fatiguing, it is recommended that no one be assigned to do this type of work for more than four consecutive hours. A person's health, emotions, working conditions, and other factors can influence resolution reading; hence, it is very important to consider these factors when assigning an individual to a resolution reading task.

Finally, all readers shall be trained and monitored as prescribed in Section IV of this standard.

3.5 READING AND REPORTING OF SYSTEM-RELATED TRIBAR TEST TARGET RESOLUTION IMAGERY

3.5.1 Data Acquisition

This subsection deals with tribar imagery produced by aerial and satellite camera systems during either flight engineering operations or ground testing. This standard shall apply regardless of the configuration of the tribar test target.

In all cases, imagery of this type is affected by a variety of conditions. For the flight case, atmospheric conditions, exposure and relative motion between the camera and the test target (image smear) will affect the results. In ground testing, various camera and test setup parameters will affect the final results. Accurate estimates of the effects of these various parameters form an essential part of the analysis and reporting of this type of tribar target resolution. All test conditions and variables should be carefully noted and logged along with the resolving power data being collected.

3.5.2 Reading and Recording Tribar Test Target Imagery Results

3.5.2.1 Source of the Data

When reading resolving power targets aimed at evaluating and/or reporting on camera system performance only, the original negative shall be employed. When performing studies aimed at evaluating reproduction processes, the appropriate duplicates shall be employed. In both cases, the readings shall be made from the emulsion side of the film.

3.5.2.2 Number of Readers

Each tribar image shall be read by a minimum of three individuals; each individual should make his readings independently. However, the pressures of time and/or the quantity of data to be read often make this requirement impractical. Each program office shall decide when this requirement can be waived. If other than three readers are employed, the number shall be reported. This problem most frequently occurs during preflight system testing.

3.5.3 Viewing Equipment and Conditions

The following paragraphs specify the viewing equipment and conditions that shall apply when reading resolution of NRP systems.

3.5.3.1 Microscope

A variable power, binocular microscope such as the Bausch & Lomb Stereo Zoom 7 or equivalent shall be used to evaluate the imagery.

The magnification of the viewing microscope shall be between 0.5 and 1.0 times the resolving power (in cycles per millimeter) that is expected to be read.

For resolving powers under 1000 cycles/mm, the numerical aperture of the objective shall be not less than 0.001 times the resolving power that is being determined.

The microscope shall be tested using high contrast tribar and point source targets. There should be no visible axial color fringing (primary or secondary color) and no astigmatism at the magnifications used for viewing. In general, the image of the high contrast test targets at the expected frequency shall appear sharply defined, i.e., limited in quality only by the observer's acuity.

The usable field of view of the microscope shall be determined with regard to this specification. In use, the targets shall always be oriented to this area. The usable field of view shall be defined as that area wherein quality appears at least equal to that on the optical axis. Within the usable field of view, field curvature shall be well within the accommodative range of the observer's eye, i.e., no refocusing is required.

3.5.3.2 Light Source

The light source shall be variable and of sufficient intensity. The intensity range shall be such that the luminance of the image seen by the reader can be adjusted to a comfortable level. In general, sufficient intensity means that the maximum available intensity is seldom required and the reader does not feel that additional light would result in improved reading conditions. The light source should be diffuse and have a continuous spectrum. In particular, a source having spectral lines shall not be used when evaluating color materials.

3.5.3.3 Ambient Light Level

The ambient light level shall be adjustable or the viewing area shielded from stray light to prevent the possibility of glare or reflection in the viewing microscope.

3.5.3.4 Vibration

The viewing equipment shall be free of noticeable vibration when viewing imagery at the highest magnification to be employed.

3.5.4 Recording Data

3.5.4.1 Mission Data

For mission flight engineering tests, the following data shall be recorded:

A. Resolution in terms of tribar element number.

B. Target orientation with respect to line-of-flight.

C. Any defects in the target display.

D. Any unusual conditions such as heavy haze or high smear rates.

3.5.4.2 Ground Test Data

For ground testing, the following data shall be recorded:

A. Resolution in terms of tribar element number.

B. Target orientation, i.e., in-track or cross-track.

C. Test conditions under which data was acquired.

3.5.5 Reporting of Mission-Related Data

3.5.5.1 Calculations

For the purpose of reporting tribar resolution results, the following calculations shall be performed:

A. Normalize each reading to 2:1 contrast, when possible, and report both normalized and actual readings. NOTE: At the time of this writing, the normalization standard had not been completed. Until this standard is published, resolution data should be normalized as directed by the program office.

B. For each sample, determine the average resolution of the reader data for in-track, cross-track, and the geometric mean in terms of both GRD and RP.

C. When sufficient replicate samples exist, the standard deviation and 95% confidence limit about the mean shall be reported. For example if, on a particular mission, 10 CORN test targets are acquired at nominal acquisition conditions, then these constitute a set of replicates.

3.5.5.2 Restrictions on Sample Population

As a part of any report on system performance, the restrictions placed on the tribar sample population should be stated. For example, individual samples may be disregarded because of focus error, excessive smear, weather conditions or target defects. Statements of restrictions should be quantitative whenever possible, e.g., state the amount of focus error tolerated.

3.5.5.3 Summary of Data

The data shall be summarized in a tabular form and will include in-track/cross-track medians and ranges in units of RP and GRD; geometric means of the in-track/cross-track medians for each frame; and the number of resolution readers employed.

3.5.5.4 Raw Data

When recording mission results, the following raw data shall be recorded in the interest of preserving and accumulating data for future studies:

A. Readings from each target for each reader.

B. Apparent test target contrast.

C. Target contrast on the ground.

D. Photographic scale.

E. Mission and test target related data.

3.5.6 Reporting of Ground Test-Related Data

Chamber testing of cameras requires slightly different reporting than that of the on-orbit engineering photography. For chamber test photography, the following reporting shall be made:

A. Contrast of the test target employed.

B. The progression of the test target.

C. The mean, 95% confidence in the mean, and the standard deviation about the mean.

The results will be reported as in-track, cross-track, and geometric mean values. The procedure for averaging data shall be as follows: the geometric mean of each in-track and cross-track value (for a single sample) shall be made; the arithmetic mean of the geometric means will then constitute the mean performance for the data set under evaluation.

3.6 FILM RESOLUTION DETERMINATION

3.6.1 Data Acquisition

3.6.1.1 Source of the Data

This section of the resolution standard is concerned with the reading, analysis, and reporting of the resolving power of photographic films. When testing the resolving power of photographic films, a set of resolution test target exposures is made on the product of interest in a camera whose lens limiting resolution exceeds by a factor of at least three the limiting resolution of the film being tested, and the images are visible (by some type of development) to an observer when viewed under magnification.

3.6.1.2 General Procedure for Producing Resolution Exposure Strips

It is well known that the resolving power of a material depends on the exposure used. The resolving power passes through a maximum as the exposure is increased from a value at the toe of the characteristic curve to a value at the shoulder. Furthermore, the measured value of the resolving power will pass through a maximum as the focus setting is given successive values that vary from one side of correct (optimum) focus to the other.

The resolving power is defined below as the maximum of the measured values with respect to the focus setting. In brief, the procedure is to first determine the focus setting found to be optimal for the material of interest by photographing a high contrast (greater than 20:1) target and changing focus in a series of small increments. After the best focus position has been determined, the target of interest (having any contrast desired) is photographed using an exposure series that brackets optimum exposure and covers the range from underexposure to overexposure.

In a typical laboratory, the testing procedure for resolution target exposures consists of placing 11 exposures of a specific test target on the film at uniformly incremented intensity variations. The formats usually cover a 1.00 log E range in 0.10 log E increments, or a 2.00 log E range in 0.20 log E increments, depending on the density range of the film to be tested. There are 11 exposure variations which need to be recorded. The format for an exposure series is shown in Figure 3-5.

The test target recommended for film testing is the 1966 ASA Target shown in Figure 3-6.

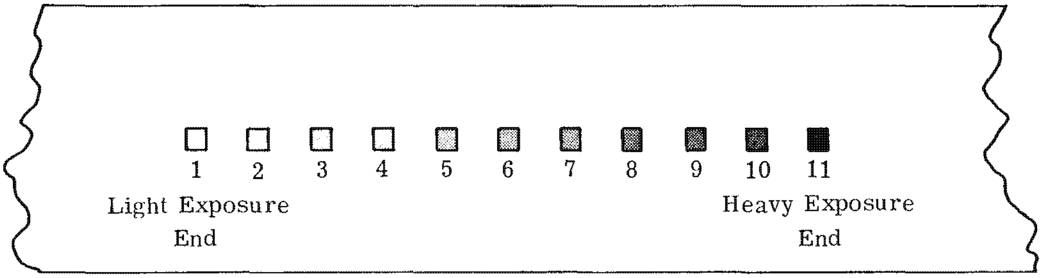
3.6.2 Reading Tribar Data

3.6.2.1 Number of Readers

The number of readers shall be the same as required in paragraph 3.5.2.2.

EXPOSURE FORMAT FOR RESOLUTION TARGETS

(Exposures from Resolution Target Camera)



2.0 Log Exposure Range

Exposure Position	Neutral Density Filter
1	2.0
2	1.8
3	1.6
4	1.4
5	1.2
6	1.0
7	0.8
8	0.6
9	0.4
10	0.2
11	0.0

1.0 Log Exposure Range

Exposure Position	Neutral Density Filter
1	1.0
2	0.9
3	0.8
4	0.7
5	0.6
6	0.5
7	0.4
8	0.3
9	0.2
10	0.1
11	0.0

FIGURE 3-5

IRARS
TRIBAR RESOLUTION STANDARD

ASA 1966 TEST TARGET

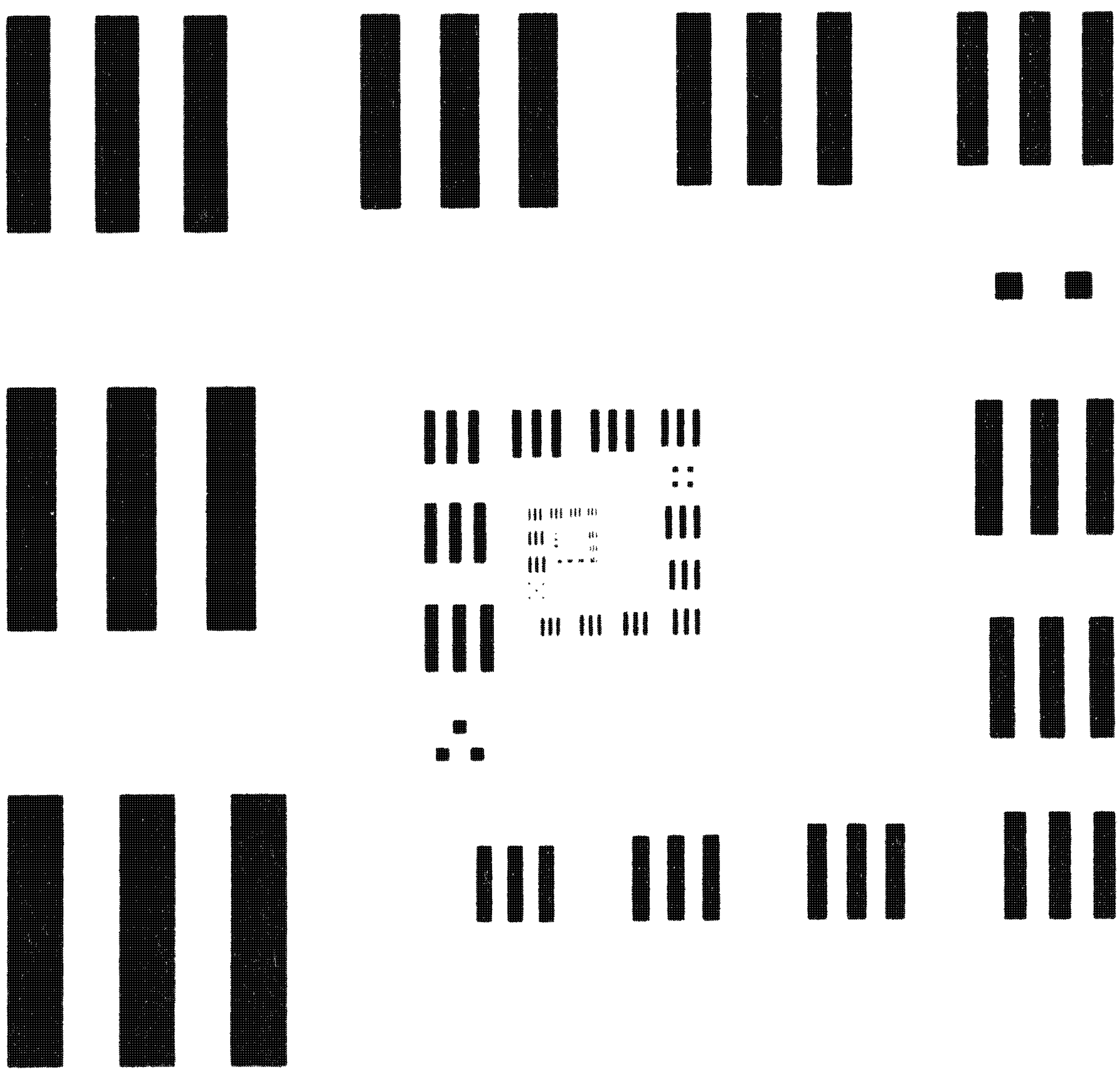


FIGURE 3-6

3.6.2.2 Reader Variability

To establish a measure of reader variability, several persons should read a set of standard test target images which should be retained for this purpose only. Data for resolving power readings should be statistically analyzed for individual and group comparison. Periodically, readers should be checked on the same set of standard test target images to establish a trend of change or to determine normal fluctuation. The construction and use of trend charts is discussed in Appendix C.

3.6.3 Viewing Equipment and Conditions

3.6.3.1 Microscope

The photographic material shall be evaluated by inspection with microscope objectives which are fully satisfactory for evaluating the photographic material. Experience has shown that the microscope body and mounting itself must be of sufficient quality and rigidity to insure positive control of focusing. To comply with this standard, microscopes and optics equivalent to a Zeiss Standard RA Routine and Research Microscope with the following accessories shall be employed:

A. Large mechanical stage with a specially designed vacuum hold-down.

B. Binocular eyepiece tube.

C. 60 watt illuminator with transformer.

D. Optics.

(1) Objectives: Epiplan, for use without coverglass, and the following magnifications/numerical apertures: 4X/0.10, 8X/0.20, 16X/0.35, and 40X/0.85.

(2) Eyepiece: 12.5X, color corrected, wide field, and for use with spectacles.

(3) Condenser: 1.3 N.A. for bright field viewing.

Additionally, the requirements of paragraph 3.5.3.1, excluding the use of a Stereo Zoom 7 type of microscope, shall be met.

3.6.3.2 Light Source

The conditions of paragraph 3.5.3.2 shall be met.

3.6.3.3 Ambient Light Level

The conditions of paragraph 3.5.3.3 shall be met.

3.6.3.4 Vibration

The conditions of paragraph 3.5.3.4 shall be met.

3.6.4 Data Analysis and Reporting

3.6.4.1 Data Analysis

The recorded group/element data should be decoded (converted to cycles/mm) and averaged geometrically for the entire reader population for each exposure increment. For large scale data handling, this can be accomplished by key punching the group/element data and having the data analysis accomplished via a computer program. As an example, the FEAT (Film Evaluation and Testing Lab) Laboratory uses a program known as RESDRX (Resolution Data Reduction). Figure 3-7 shows the RESDRX computer output for three replications of 1000:1 TTC resolution imagery.

Note that the RESDRX program provides:

A. An analysis of each reader's peak resolving power value, log E at peak, and variation from group average.

B. Statistical data for the entire reader population:

(1) Mean, high, and low resolving power (cycles/mm) for each exposure increment.

(2) ± 2 sigma limits in cycles/mm.

(3) Dispersion, expressed in percent, is calculated as:

$$D = 100 \frac{S}{\overline{X}}$$

where: D = coefficient of dispersion or relative variation.

S = one standard deviation (sigma).

$\overline{X}$ = mean value of resolving power (in cycles/mm).

NOTE: A 12% dispersion would indicate ±one target element variation in a $\sqrt[20]{10}$ array (the array of the Series 1 Test Target).

3.6.4.2 Graphical Representation of Resolving Power Data

Computer or calculated output data, such as that shown in Figures 3-7 and 3-8 can be obtained for each of the TTC levels used in the analysis. This data shall be transferred through computer or calculated curve-fit programs to the correct D log E curve to show resolving power as a function of log exposure, see Figure 3-10. Note that the peak resolution may be slightly higher than the actual observed values because exposure increments of 0.20 may not fall exactly at the peak resolution, which is compensated for by curve fitting.

Resolution curves shall be presented in logarithmic format; such presentation is more meaningful because the resolution target progression is geometric. Figures 3-9 and 3-10 compare two plots of the same 1000:1 TTC data, linear and logarithmic respectively, which graphically demonstrate the differences in presentation. Another advantage of the logarithmic plot is that most of the products of interest in the aerial film reconnaissance community can be recorded on graph paper of the same scale,

FIGURE 3-7

SAMPLE OF THE "RESDRX" COMPUTER PROGRAM OUTPUT

PLOT NUMBER = 1

CARD MATCHING INFORMATION

LOG	PRO	EMUL	BATCH	FILTER	INC	TOC	READER	STRIP
3410		3414	009		0.2	1000		

SELECTED INDIVIDUAL CARDS

LOG	PRO	EMUL	BATCH	FILTER	INC	TOC	READER	STRIP	MAX LOG E	MAX RES
3410		3414	009		0.2	1000	A	1		
									0.98	722.227
3410		3414	009		0.2	1000	A	2		
3410		3414	009		0.2	1000	A	3		
3410		3414	009		0.2	1000	B	4		
									1.01	693.383
3410		3414	009		0.2	1000	B	5		
3410		3414	009		0.2	1000	B	6		
3410		3414	009		0.2	1000	C	7		
									0.98	716.398
3410		3414	009		0.2	1000	C	8		
3410		3414	009		0.2	1000	C	9		

STATISTICAL INFORMATION

MEAN	104.70	201.71	302.77	403.83	585.28	708.87	525.76	306.90	228.99	129.27	59.79
HIGH	117.37	234.36	331.08	524.52	740.28	831.42	587.76	331.08	262.26	130.76	66.03
LOW	93.19	186.00	262.26	372.00	466.86	587.76	466.86	262.26	208.32	117.37	52.45
+2SIG	116.81	243.26	349.89	504.14	745.10	891.96	611.30	356.95	273.76	138.20	70.48
-2SIG	92.59	160.15	255.65	303.52	425.46	525.77	440.22	256.85	184.21	120.34	49.10
DISPERSION	5.78	10.30	7.78	12.42	13.65	12.91	8.13	8.15	9.78	3.45	8.94

MAXIMUM RESOLUTION IS 709.87

MAXIMUM RESOLUTION OCCURS AT RELATIVE LOG EXPOSURE OF 0.986

DEVIATION FROM SUMMARY MAX

READER	LOG E DEVIATION	PERCENT RES DEVIATION
A	-0.01	1.74
B	0.02	-2.32
C	-0.01	0.92

RANGE OF RES DEVIATION IN PERCENT

AVERAGE(+)= 1.33 AVERAGE(-)= -2.32 AVERAGE(+ OR -)= 1.83

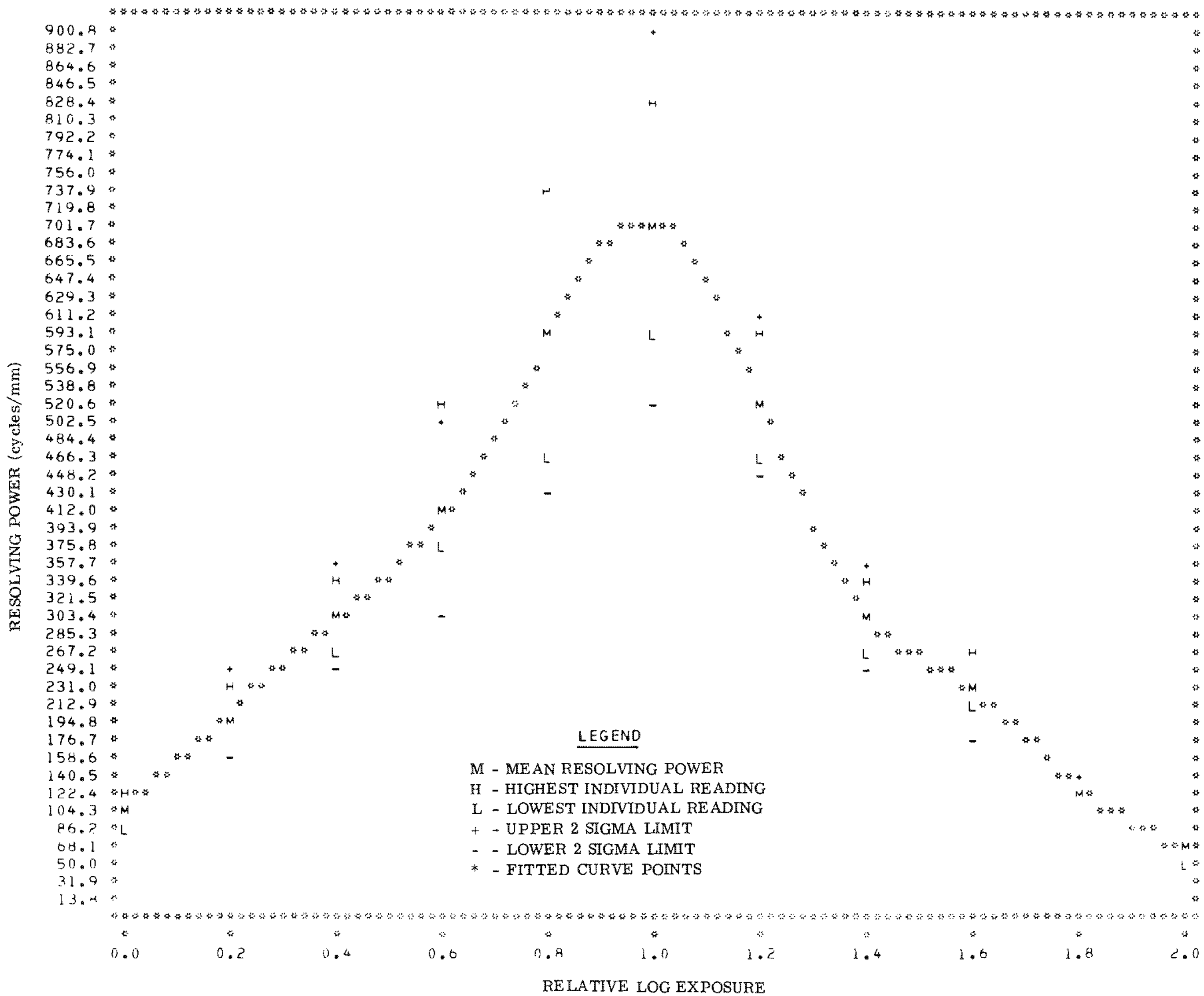
TOP SECRET-HEXAGON / GAMBIT

Approved for Release: 2018/07/31 C05106617

TOP SECRET-~~HEXAGON~~ / GAMBIT

FIGURE 3-8

MATHEMATICALLY FITTED COMPUTER OUTPUT CURVE



TOP SECRET-~~HEXAGON~~ / GAMBIT

BYE 15313-73

Handle via Byeman
Controls Only

IRARS
TRIBAR RESOLUTION STANDARD

RESOLUTION DATA IN LINEAR FORM

CURVE	TTC	RES	LOG E
1	1000	710.	$\bar{1}.83$
2	3.24	347.	$\bar{1}.81$
3	1.70	205.	$\bar{1}.53$

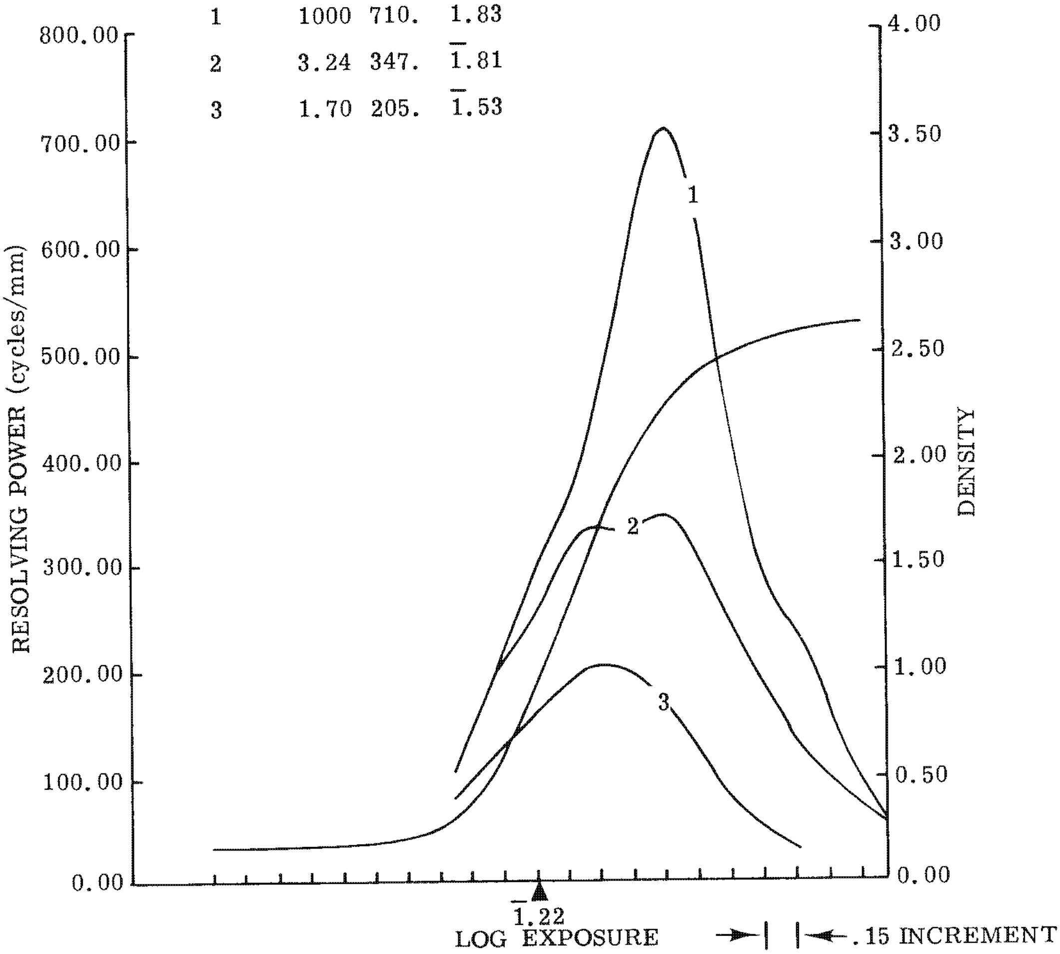


FIGURE 3-9

BYE 15313-73

RESOLUTION DATA IN LOGARITHMIC FORM

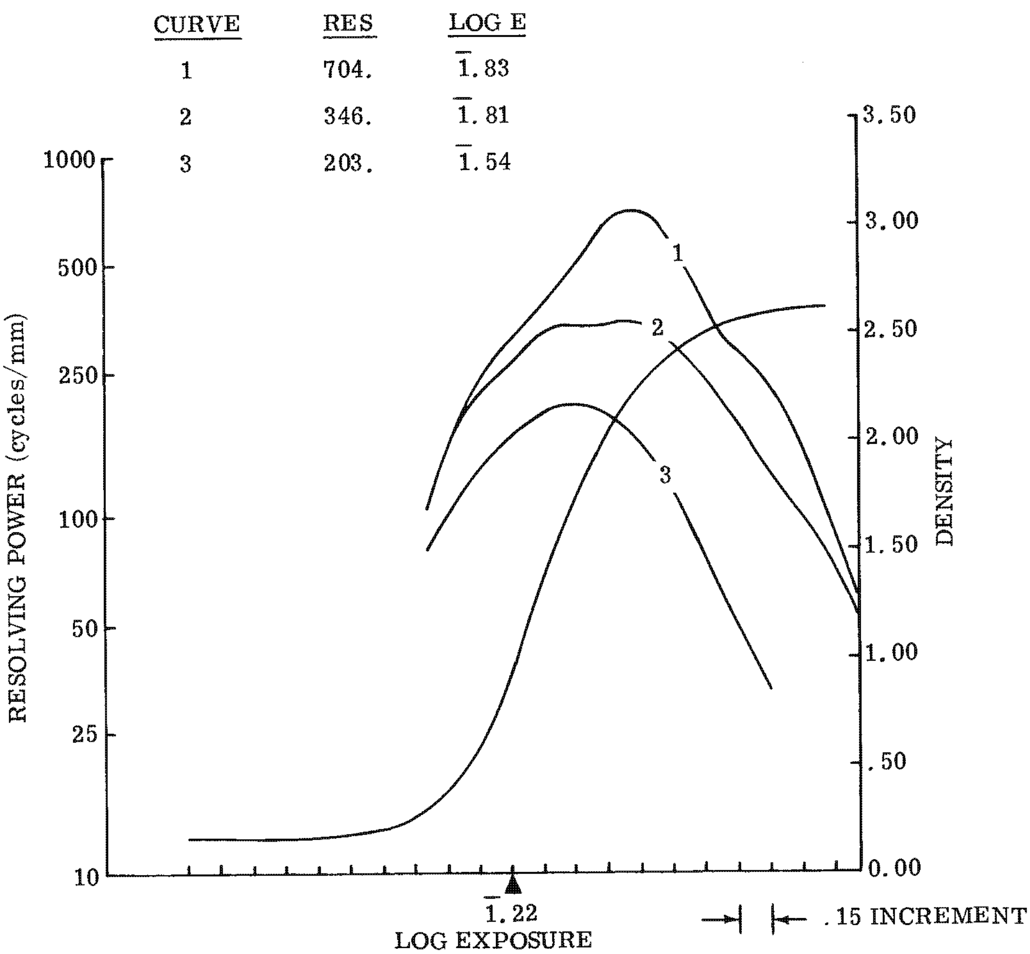


FIGURE 3-10

rather than the expanding or contracting scale normally used for the linear presentation. To comply with this standard, three-cycle semi-logarithmic graph paper shall be used.

In order to simplify the location of specific resolution, density, and log E values, graph-grids shall be incorporated or tabulated data shall be presented. Grids or tabulated data provide a rapid and convenient reference for those who are interested in finer detail than can be visually derived from graphs without grid overprints.

3.6.4.3 Reporting of Peak Resolution

Peak resolution values shall be accompanied by a ± 2 sigma limit. The user will then be able to have a better appreciation of the variability in the data and will not assign undue importance to a small shift in the mean. The TTC shall be specified so as to prevent improper comparison of resolution values.

SECTION IV

READER TRAINING AND QUALIFICATION

4.1 SCOPE

This section outlines the certification and training program for resolution readers. The program consists of four phases which are described in paragraph 4.3 and summarized in Table 4-1. It is intended to assure that they approach and execute their task from a common point of view using techniques prescribed by this standard. Those readers with prior experience will undergo an abbreviated program which concentrates on the development of consistent application of the criterion of reasonable confidence. Detailed statistical procedures for this purpose are provided in Appendix C. Inexperienced readers will complete the entire program. IRARS Tribar Image Training Sets will be furnished to each participating resolution reading activity. Others desiring copies should request them in writing from the Chairman, IRARS-TF.

4.2 DESCRIPTION OF TRIBAR IMAGE SETS

4.2.1 Tribar Image Training Set (TRITS)

The Tribar Image Training Set is an unclassified set of sixty paper prints that are enlargements of model CORN type resolution targets. The tribar images are purposely degraded by a variety of smear, focus, and exposure conditions. The set of sixty prints will be presented to the students during Phase III in groups of 15 as outlined in paragraph 4.3.3. The size and content of the TRITS can be expanded or revised in the future at the discretion of the Training Committee. Each resolution reader instructor will have a copy of the TRITS for use in his training program.

4.2.2 Master Tribar Image Test Set (MTRITS)

The Master Tribar Image Test Set consists of thirty-four unclassified 2 1/4" x 2 1/4" glass mounted film chips which include a variety of resolution targets; e.g., CORN, ANSI Standard, USAF 1951. The MTRITS provides the standard for certification of each resolution reader. It is a one-of-a-kind set of tribar images, under the direct control of the Training Committee Chairman, and will be brought to each resolution reading activity for use in periodic certification.

4.3 READER TRAINING AND CERTIFICATION PROGRAM

A four phase reader training and certification program has been developed by the members of the IRARS-TF Standing Committee on Training. It is described below and summarized in Table 4-1.

4.3.1 Phase I

In this phase, new readers are taught the concepts of resolution and test target design presented in Section II of this IRARS Standard and the local procedures used in reading and reporting resolution. Using illustrations provided in Appendix B, and other appropriate visual aides, the new readers will be taught the resolution reading criteria contained in Section III.

4.3.2 Phase II

The experienced reader will begin training at this point along with those completing Phase I. The criterion of reasonable confidence will be explained and discussed with both experienced and inexperienced readers. The need to establish standard resolution reading rules and procedures throughout the community will be emphasized. The main purpose of this phase is to motivate resolution readers to properly use the criterion of reasonable confidence and to comply with the IRARS Tribar Resolution Standard.

4.3.3 Phase III

This phase concentrates on the actual application of resolution reading criteria. Using the TRITS, the reader will:

A. Read fifteen tribar images and record his answers on IRARS Form 1, see Figure 4-1.

B. Check his answers against those supplied with the TRITS.

C. Compare and review his wrong readings with the established standard readings until he understands the proper application of the reading criteria and is able to recognize the threshold of resolution.

This procedure will be repeated four times each day using different groups of fifteen images until the reader demonstrates his ability to read the four sets of fifteen images with results that satisfy the statistical criteria established in Appendix C, paragraph C.2.

4.3.4 Phase IV

This portion of the training program provides for initial and periodic testing/checking of reader accuracy and consistency. After successful completion of Phase IV, the trainee is considered certified.

The instructor will describe the MTRITS and briefly outline the statistical analysis to be carried out with the reading data. The trainee will then read the thirty-four images in the MTRITS and record his answers on IRARS Form 2 (Figure 4-2). The instructor will perform the statistical analysis described in paragraph C.2 to determine if the trainee is certified. If not certified, the trainee will repeat Phase III and be retested.

In this phase, readings should be made with the equipment and under the conditions to be used operationally. The reader will be required to undergo a resolution reading performance check at least once every six months.

4.3.5 Training Scheduling

Each resolution reader will be trained and certified as outlined above before assignment to resolution reading duties. Following initial certification, the reader will normally retake Phases II and III once per year, and Phase IV semi-annually. However, failure to pass the certification test or failure to remain within statistical control will require the reader to be retrained and/or recertified. The extent of retraining will be at the discretion of the Standing Committee member for the organization concerned.

TABLE 4-1

SUMMARY OF THE READER TRAINING & CERTIFICATION PROGRAM

Phase	Designed For	Approximate Duration	Training Schedule After Initial Certification	Training Materials
I	New readers	1 day	0	IRARS Tribar Resolution Standard Sections II, III, and Appendices A, B; Visual Aides
II	New/experienced readers	1 day	Annual or as required	IRARS Tribar Resolution Standard Appendix B; Visual Aides
III	New/experienced readers	3-4 days	Annual or as required	TRITS; IRARS Form 1
IV	New/experienced readers	2-3 hours	Semi-annual or as required	MTRITS; IRARS Tribar Resolution Standard Appendix C; IRARS Form 2

4.4 PROGRAM IMPLEMENTATION

4.4.1 IRARS-TF Standing Committee

A Standing Committee on training for tribar resolution has been established to implement the certification and training program. The Committee members represent the following organizations:

National Photographic Interpretation Center (NPIC/APSD), Training Chairman

Secretary of the Air Force [redacted] (b)(1)

Eastman Kodak Company (b)(3)

Perkin-Elmer Corporation

Itek Corporation

Defense Mapping Agency Aerospace Center (DMAAC)

Defense Intelligence Agency (DIA/DC-6)

Central Intelligence Agency (CIA/OD&E)

The Standing Committee prepared both the TRITS and MTRITS imagery sets. Standard resolution readings for these sets were established by reading the targets as prescribed in this standard. Each member of the committee will conduct the initial, periodic, and remedial training within his organization. He is responsible for bringing to the attention of the Training Committee Chairman any problem encountered during this training as well as suggestions for improving the overall program. Suggestions and comments will be reviewed by the Training Chairman and forwarded with recommended action to the IRARS-TF Chairman.

4.4.2 Resolution Reader History File

Each Standing Committee member will maintain a written record of resolution reader training and periodic follow-up sessions for each reader in his organization. As a minimum, the file will contain:

A. Completed Form 1 (TRITS) and Form 2 (MTRITS).

B. Listing of the standard resolution readings for the TRITS.

C. Training schedules showing dates for follow-up sessions.

D. Individual and group control charts.

TRITS WORK SHEET

NAME ____________
DATE ____________
TRITS SET NUMBER ________

HORIZONTAL

	READING	CORRECT ANSWER	DIFFERENCE
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
		MEAN Δ	
		STANDARD DEVIATION	
		CONFIDENCE INTERVAL	

VERTICAL

	READING	CORRECT ANSWER	DIFFERENCE
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
		MEAN Δ	
		STANDARD DEVIATION	
		CONFIDENCE INTERVAL	

INSTRUCTIONS:

1. Record readings.
2. List correct answers.
3. Subtract correct answers from readings to obtain difference, i.e.,

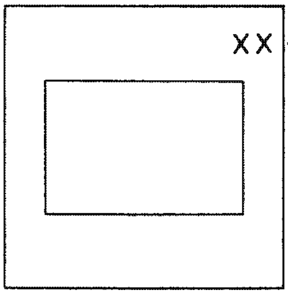
   Difference = (reading) - (correct answer).
   Plus (+) difference indicates reading is too high.
   Minus (-) difference indicates reading is too low.

4. Instructor will calculate mean, standard deviation, and confidence interval when necessary to check your progress.

IRARS Form 1

FIGURE 4-1

IRARS
TRIBAR RESOLUTION STANDARD



PLEASE KEEP SLIDE NUMBER IN THIS POSITION

NAME ____________

DATE ____________

MTRITS ANSWER SHEET

(Δ= reading - standard)

	HORIZONTAL		VERTICAL	
	Reading	Δ	Reading	Δ
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
MEAN Δ				
STANDARD DEVIATION				

IRARS Form 2

FIGURE 4-2

APPENDIX A

EXISTING TARGET DESCRIPTIONS

The test targets most commonly used by the NRP community are described below.

A.1 MOBILE RESOLUTION TARGETS

The design of the mobile CORN resolution target, commonly called 51/51 Tribar Target, has a 5:1 aspect ratio and a nominal 5:1 contrast. A typical 51/51 deployment along with the basic target parameters is shown in Figure A-1. The target consists of two 381 foot long legs. Typically, each leg is comprised of 39 tribar elements which progressively decrease in size by a factor of $\sqrt[6]{2}$, except for elements 1 and 2. (A small number of experimental 51/51 Tribar Targets are currently in use and are displayed with an extra panel near each leg. The extra panel has a $\sqrt[12]{2}$ progression starting with element 18.5.) Each element is separated by a blank space equal to twice the width of the succeeding smaller bar. For ease in handling, each leg of the target is comprised of nine panels. The target is normally displayed with one leg parallel and the other perpendicular to the line of flight. Table A-1 gives the basic test target data; conversion of the GRD values to resolving power in cycles/mm requires calculation involving the equations discussed in Section II.

A.2 TEST CHAMBER COLLIMATOR RETICLE RESOLUTION TARGETS

The following types of resolution targets are in the 1200 series system chamber reticles: (1) low contrast (2:1), (2) high contrast ($>$100:1), and (3) visual edge matching (VEM) calibration. These resolution targets use a $\sqrt[12]{2}$ progression. Figure A-2 indicates their locations in the collimator target reticles.

A.2.1 Low and High Contrast Resolution Targets

The low contrast and high contrast targets are similar in layout; see Figure A-3. These targets are the same as the USAF 1951 Target with relation to aspect ratio, contrast ratio, and bar spacing. Table A-2 lists the basic test target information on the low contrast targets only since these are the most commonly used.

A.2.2 VEM Calibration Target

Figure A-4 presents the tribar configuration of the VEM calibration target. This target allows direct calibration of image quality as measured by the VEM technique to equivalent tribar resolution for each 1200 series camera system. The target conforms to the 5:1 aspect ratio and 2:1 contrast. Table A-3 lists the test target data of the VEM calibration target.

A.2.3 USAF 1951 Resolving Power Target

While not used extensively in the NRP, the USAF 1951 Target is mentioned because it is so widely known. Figure A-5 illustrates the configuration of the standard USAF 1951 Resolving Power Target. The progression of the standard USAF 1951 Target is presented in Table A-4.

TABLE A-1

SUMMARY OF 51/51 TRIBAR TEST TARGET
CHARACTERISTICS DATA

Material	:	Canvas or Nylon	
Contrast Ratio:		5:1	
Progression	:	$\sqrt[6]{2}$	
Reflectance	:	Bar	33%
		Background	7%

Bar Dimensions

Bar	Width	Length
Largest	8 feet	40 feet
Smallest	.56 inch	2.8 inches

Ground Resolved Distance:

Panel	Element No.	GRD	Panel	Element No.	GRD	Panel	Element No.	GRD
1	1	16'	7	14	27"	9	27	6"
2	2	12'	8	15	24"		28	5.4"
3	3	8'		16	21.4"		29	4.7"
	4	85.5"		17	19"		30	4.2"
4	5	76.2"		18	17"		31	3.7"
	6	67.8"		19	15.1"		32	3.4"
5	7	60.5"		20	13.5"		33	3"
	8	53.8"		21	12"		34	2.6"
6	9	48"	9	22	10.7"		35	2.4"
	10	42.7"		23	9.5"		36	2"
	11	38"		24	8.5"		37	1.7"
7	12	34"		25	7.5"		38	1.4"
	13	30.2"		26	6.7"		39	1.1"

TABLE A-2

SUMMARY OF THE 1200 SERIES TEST CHAMBER
RESOLUTION TARGETS CHARACTERISTICS DATA

Contrast Ratio: Low 2:1

High >100:1

Progression : $\sqrt[12]{2}$

Resolving Power at Film Plane (cycles/mm):

Element Number	Group Number 1	2	3	4	5
1	71	100	143	200	283
2	76	107	150	214	295
3	79	112	160	228	326
4	85	119	169	236	343
5	89	126	179	255	357
6	95	135	190	267	376

TABLE A-3

SUMMARY OF THE VEM CALIBRATION TARGET
CHARACTERISTICS DATA

Contrast Ratio: 2:1

Progression : $\sqrt[12]{2}$

Resolving Power at Film Plane (cycles/mm):

Element Number	Group Number 2	3	4	5	6	7	8	9
1	28	39	55	78	110	156	221	312
2	29	41	59	83	117	165	234	331
3	31	44	62	88	124	175	248	350
4	33	46	66	93	131	186	262	371
5	35	49	70	98	139	197	278	393
6	37	52	74	104	147	208	295	417

TABLE A-4

SUMMARY OF THE USAF 1951 RESOLVING POWER TARGET
CHARACTERISTICS DATA

Contrast Ratio: Variable among 8 plates (ranges 100:1 to 1.6:1)

Progression : $\sqrt[6]{2}$

Resolving Power at Film Plane (cycles/mm):

Element Number	Group Number -2	-1	0	1	2	3	4	5	6	7
1	.25	.50	1.0	2.0	4.0	8.0	16	32	64	128
2	.28	.56	1.12	2.2	4.5	9.0	18	36	72	144
3	.32	.63	1.26	2.5	5.1	10.0	20	41	81	163
4	.36	.71	1.41	2.8	5.7	11.4	23	46	91	182
5	.40	.80	1.59	3.2	6.4	12.8	26	51	102	204
6	.45	.89	1.78	3.6	7.1	14.3	28	57	114	228

NOTE: Apply reduction factors as appropriate.

A.3 RESOLUTION TARGETS USED FOR FILM TESTING

The FEAT Laboratory uses the American National Standards Institute Target (ASA 1966) for film testing and the Printer Standardization Master (PSM) Target for printer quality checks. These are described below.

A.3.1 ASA 1966 Target

This target is recommended for visual reading of resolving power tests for film product and processing evaluation. The finer spatial frequencies spiral toward the center of the target where elements will be near the center of the optical axis in the Microscope Resolution Target (MRT) Camera. The use of this target in conjunction with the MRT Camera conforms to ANSI Standard PH 2.33-1969. Figure A-6 shows the configuration of the ASA 1966 Target. Table A-5 lists the characteristics data of the ASA 1966 Target.

A.3.2 Printer Standardization Master (PSM) Target

This is a high quality target fabricated to conform to the same configuration as the USAF 1951 Target. It is used for producing resolving power master targets on film for printer evaluation. The target is also suitable for film testing. Figure A-7 shows the configuration of the PSM Target. Table A-6 lists the characteristics data of the PSM Target.

TABLE A-5

SUMMARY OF THE ASA 1966 RESOLUTION TARGET
CHARACTERISTICS DATA

Contrast Ratio: Variable among 14 plates (range >100:1 to 1.08:1)

Progression : $\sqrt[20]{10}$

Resolving Power at Film Plane (cycles/mm):

Element Number	Group Number 1	2	3	4	5	6	7
1	18.9	37.7	75.2	150	300	598	1193
2	21.2	42.3	84.4	168	336	671	1338
3	23.8	47.5	94.7	189	377	752	1501
4	26.7	53.3	106	212	423	844	-
5	30.0	60.0	119	238	475	947	-
6	33.6	67.1	134	267	533	1063	-

NOTE: The resolving power at the film plane is based on 189X reduction in the MRT Camera.

TABLE A-6

SUMMARY OF THE PRINTER STANDARDIZATION MASTER TEST TARGET
CHARACTERISTICS DATA

Contrast Ratio: 100:1

Progression : $\sqrt[6]{2}$

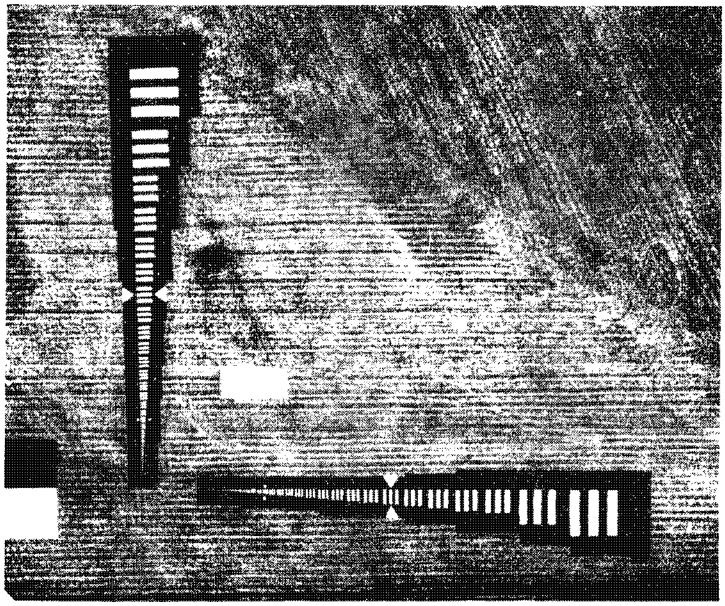
Resolving Power at Film Plane (cycles/mm):

Element Number	Group Number 6	7	8	9
1	81	163	325	650
2	91	182	365	730
3	102	205	410	819
4	115	230	460	-
5	129	258	516	-
6	145	290	579	-

NOTE: The resolving power at the film plane is based on 189X reduction in the MRT Camera.

IRARS
TRIBAR RESOLUTION STANDARD

51/51 TRIBAR RESOLUTION TEST TARGET



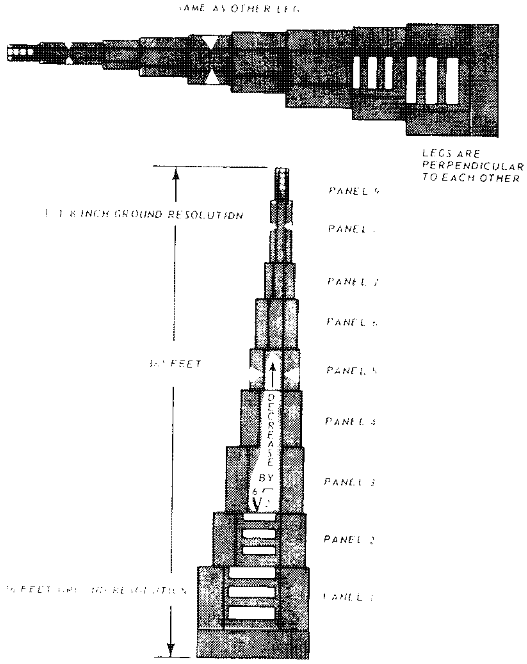


FIGURE A-1

IRARS
TRIBAR RESOLUTION STANDARD

1200 SERIES TEST CHAMBER COLLIMATOR TARGET RETICLE CONFIGURATION

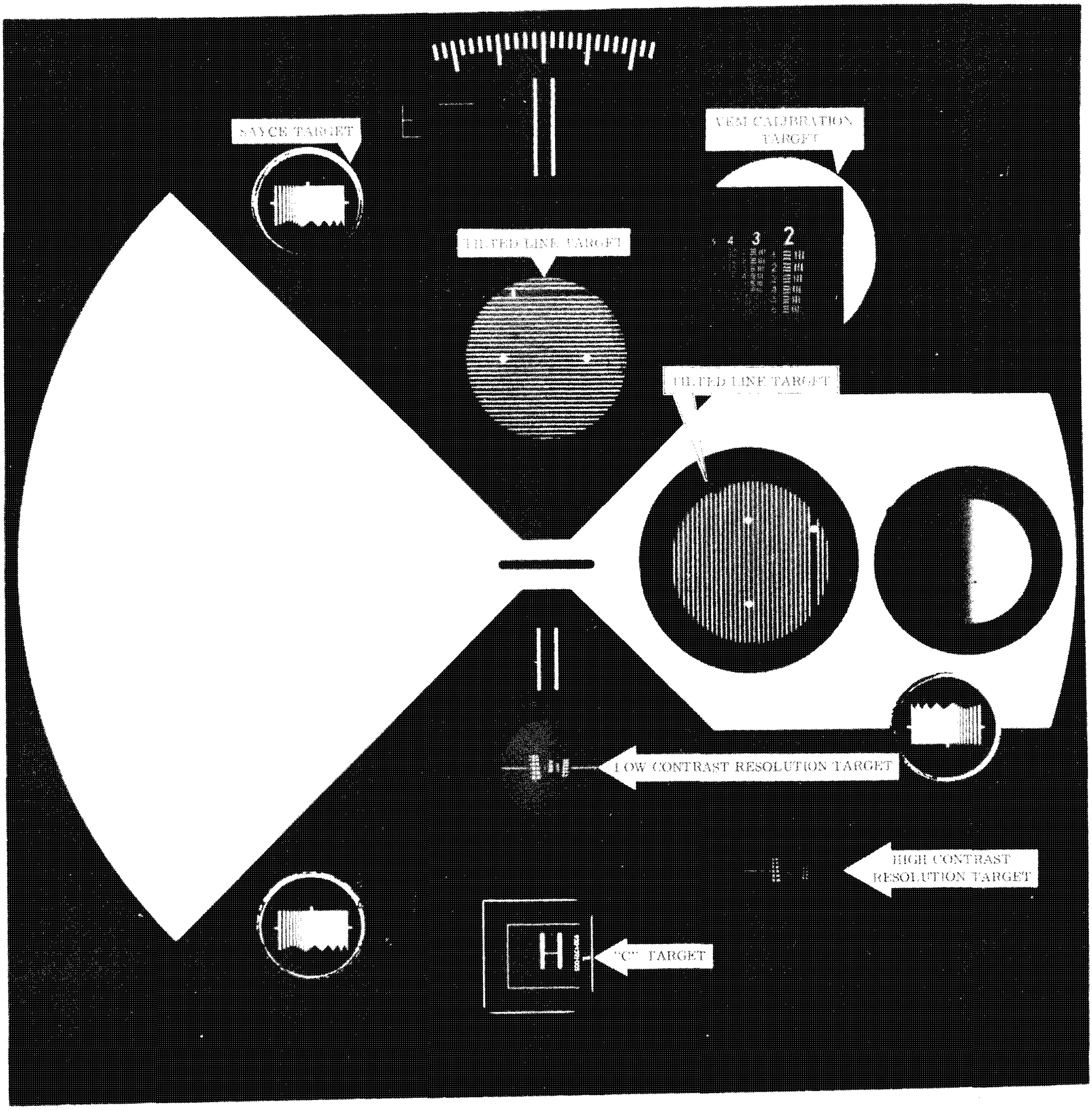
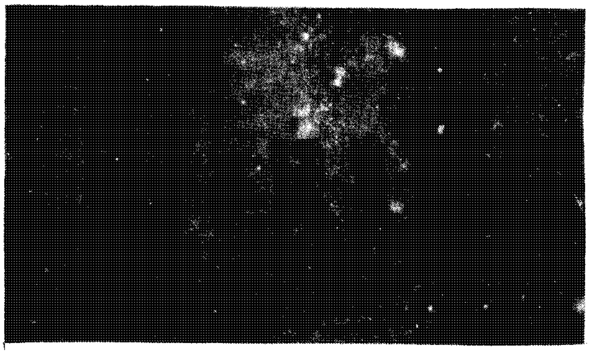


FIGURE A-5

IRARS
TRIBAR RESOLUTION STANDARD

TRIBAR CONFIGURATION OF TEST CHAMBER LOW AND HIGH CONTRAST RESOLUTION TARGETS



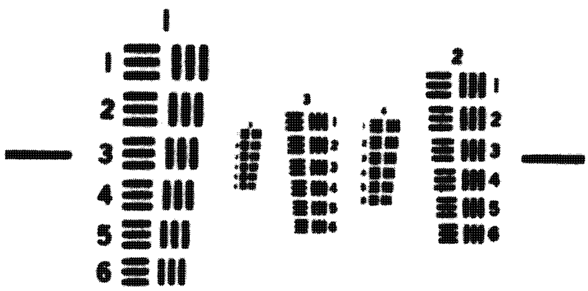


FIGURE A-3

IRARS
TRIBAR RESOLUTION STANDARD

TRIBAR CONFIGURATION OF VEM CALIBRATION TARGET

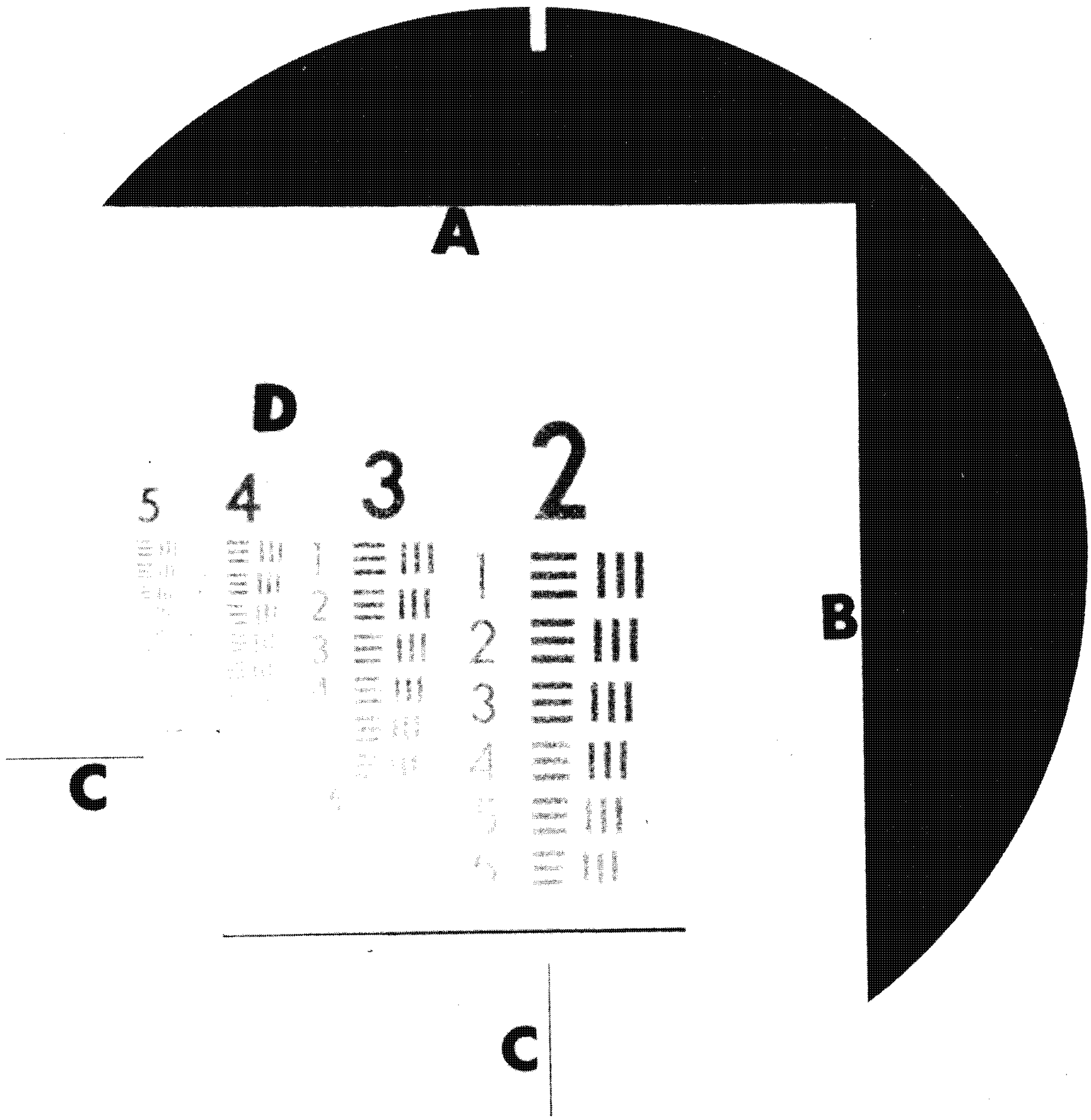


FIGURE A-4

IRARS
TRIBAR RESOLUTION STANDARD

USAF 1951 RESOLVING POWER TARGET

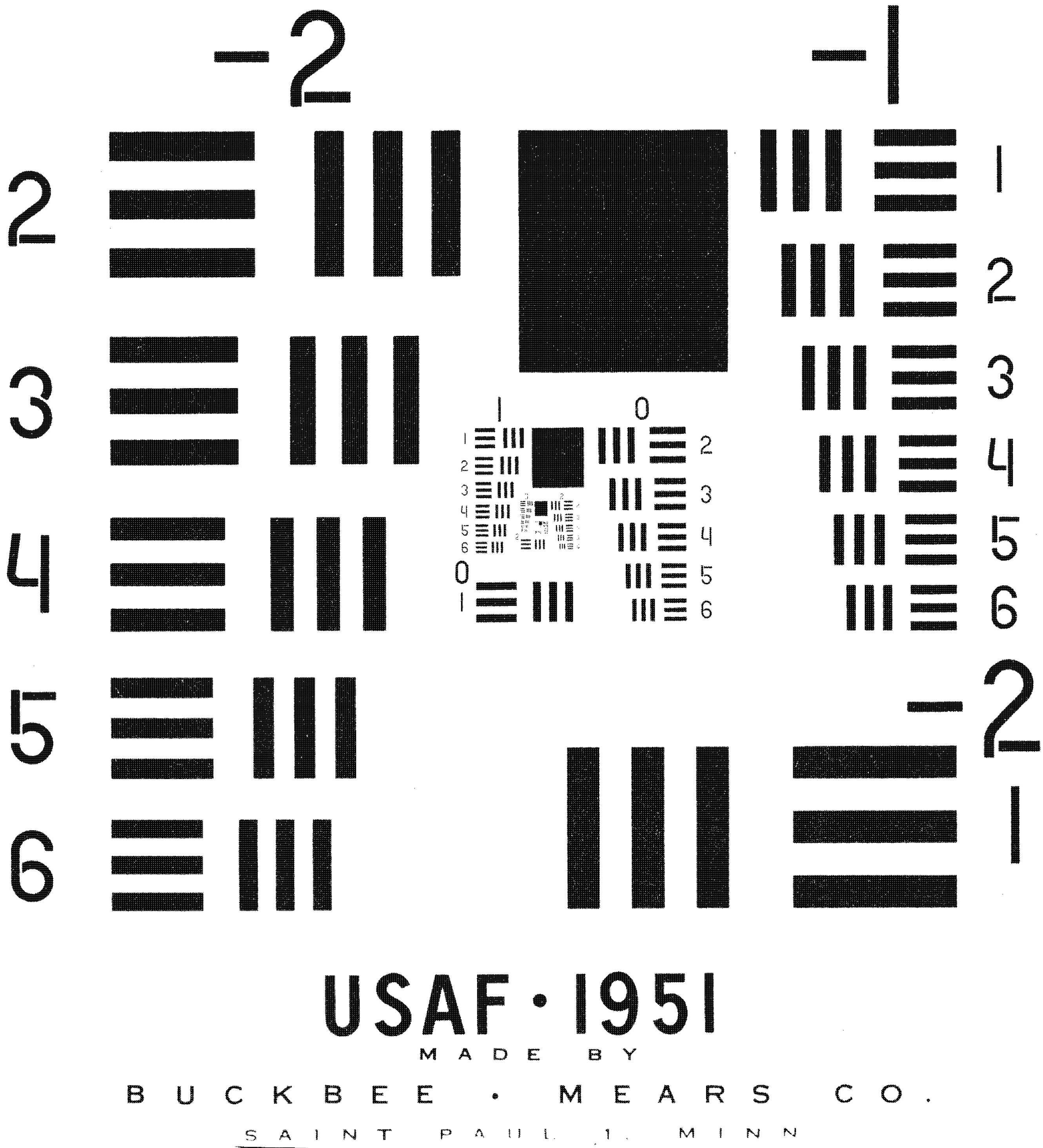


FIGURE A-6

TRIBAR CONFIGURATION OF ASA 1966 TARGET

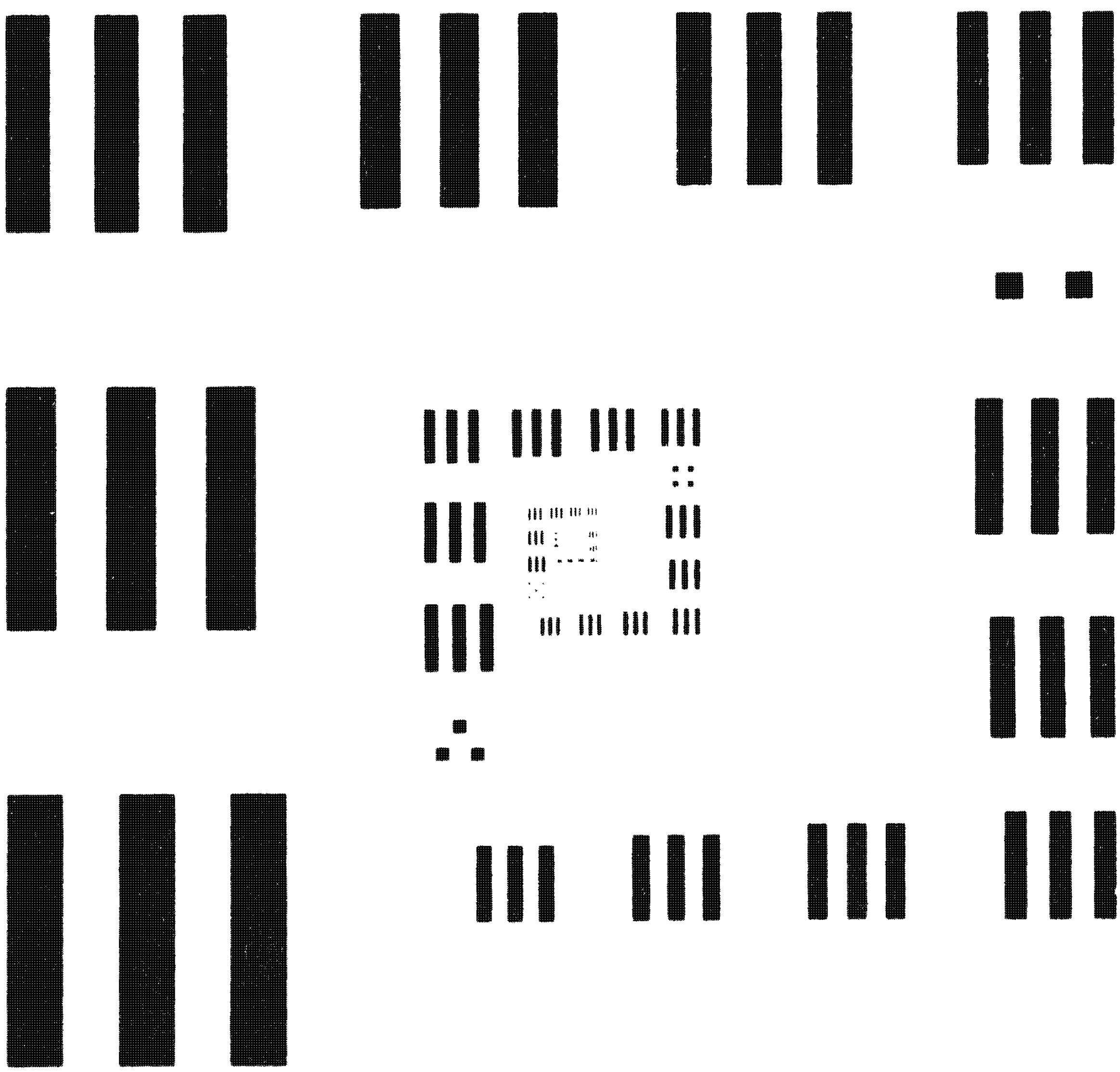


FIGURE A-7

IRARS
TRIBAR RESOLUTION STANDARD

TRIBAR CONFIGURATION OF PRINTER STANDARDIZATION MASTER TEST TARGET

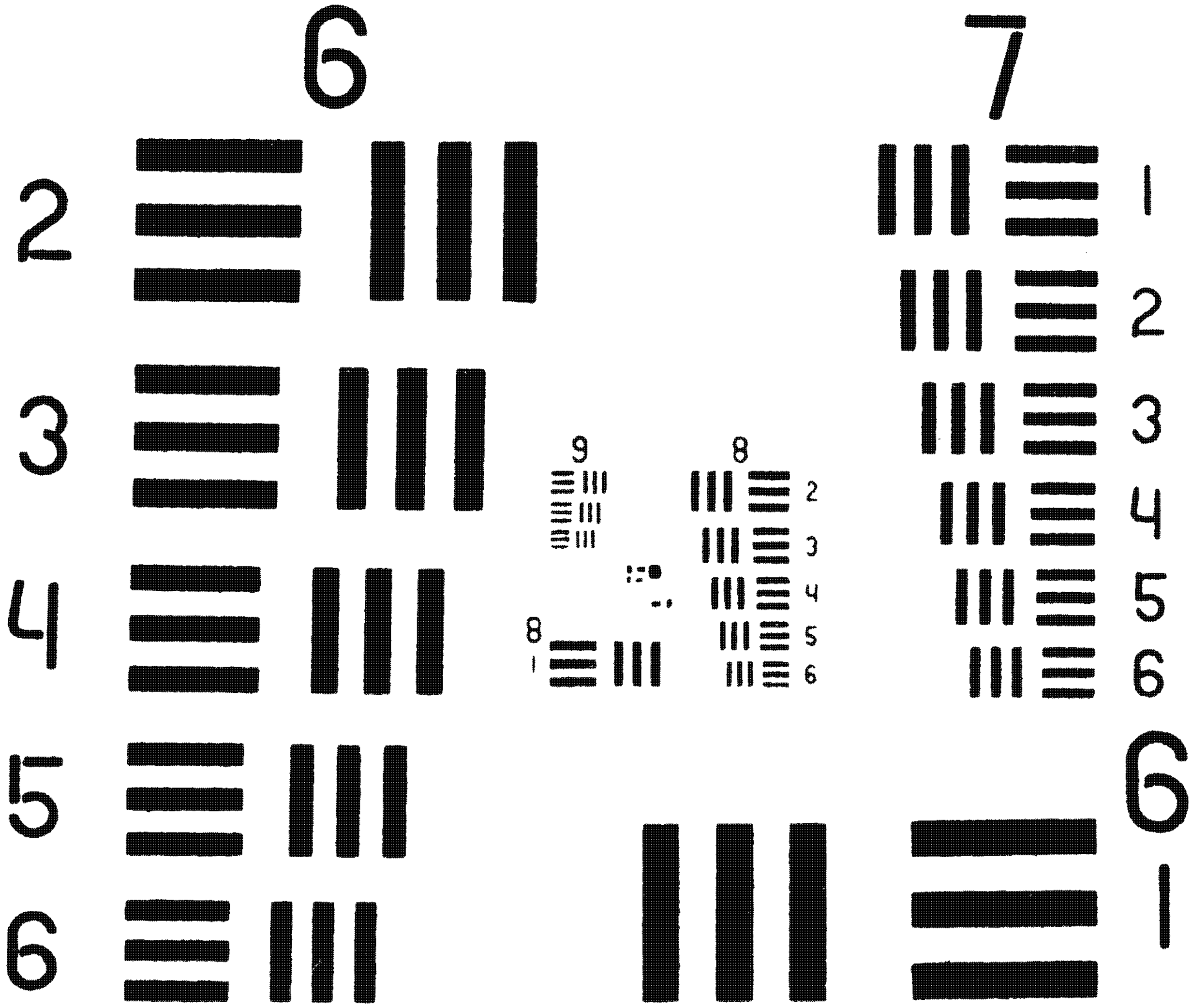


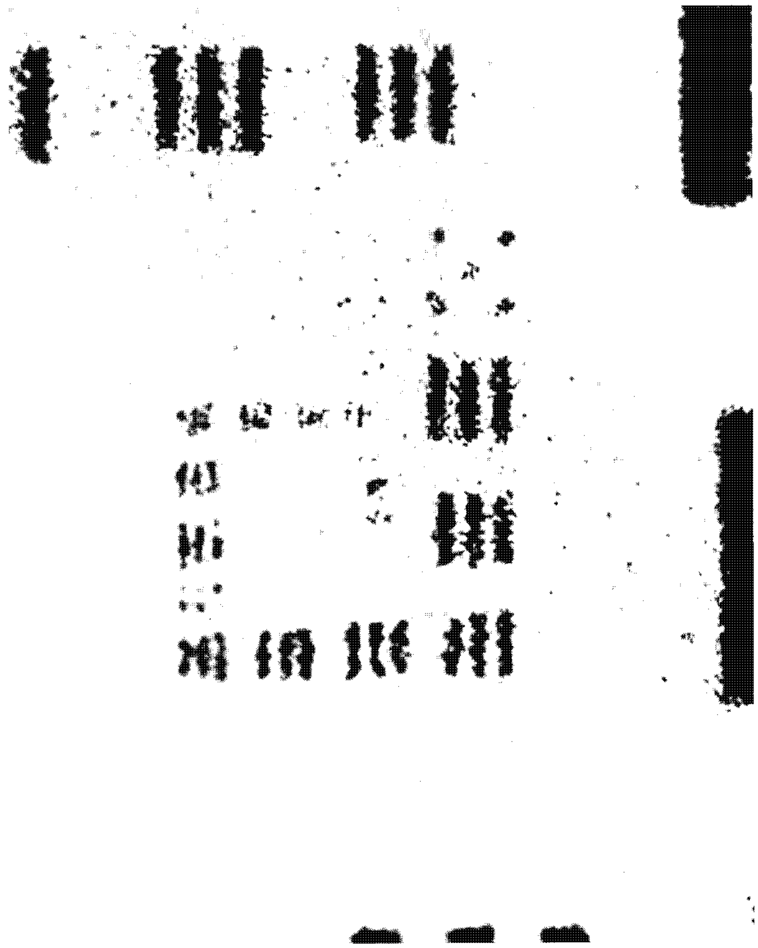
FIGURE A-2

APPENDIX B

TRIBAR READING ILLUSTRATIONS

This appendix presents examples of tribar targets which illustrate a typical range of target images encountered by the tribar reader. They provide examples of the application of the criterion of reasonable confidence as expressed in paragraph 3.3. These examples should be studied with respect to each resolved element specified in order to gain a better understanding of the criterion of reasonable confidence. The samples presented here are not all inclusive but do show the effects of films with differing grain structure and resolving power. These examples include enlargements of microphotographs taken with a microscope camera at varying magnifications and contact prints of master targets from printer test runs. The determination of the tribar element resolved in each illustration was made by members of the IRARS-TF on a set of the same images reproduced as Figures B-1 thru B-15. The range of tribar element readings is indicated, where appropriate. Also listed on each figure is the final reading which is the consensus of the group after discussion of the example. Comments are provided in those cases where, according to the established guidelines, the rationale for a final reading might need clarification. The examples on Figures B-6, B-7, and B-13 are oriented to the position normally observed by the resolution reader; a target diagram is provided at the bottom of these pages with the same orientation for ease of element identification. In these three figures "H" stands for the horizontally-oriented bars, while "V" stands for those bars which are oriented vertically.

IRARS
TRIBAR RESOLUTION STANDARD



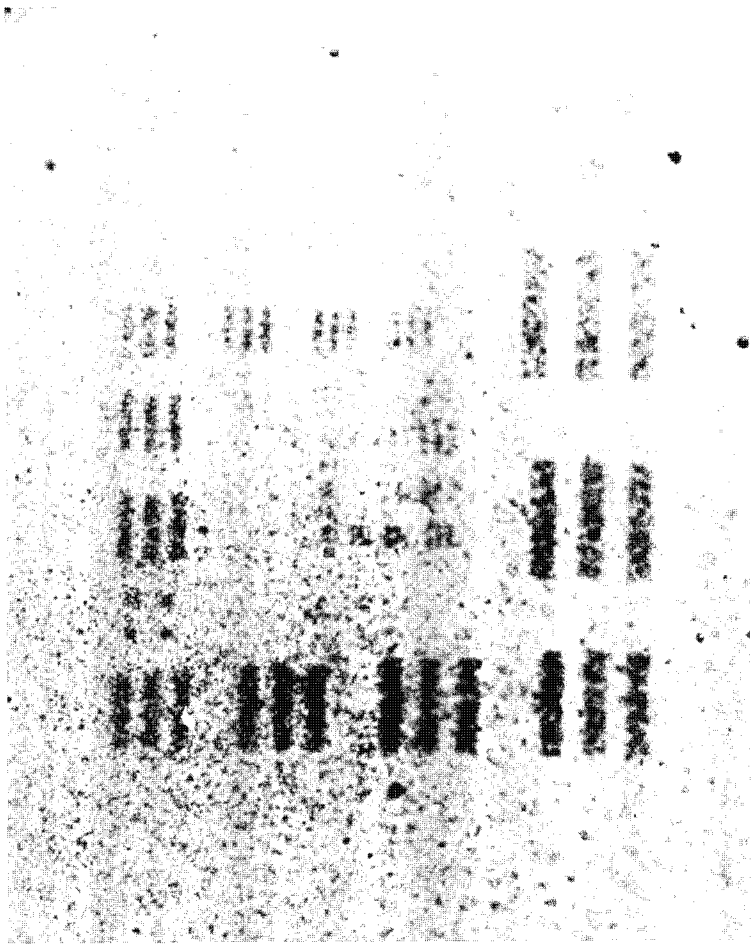
ASA 1966 TARGET

RANGE: N/A FINAL READING: 6-2

FIGURE B-2

Approved for Release: 2018/07/31 C05106617

IRARS
TRIBAR RESOLUTION STANDARD



ASA 1966 TARGET

RANGE: 4-6 TO 5-1 FINAL READING: 5-1

NOTE: Element 5-2 is not resolved, whereas 5-3 could be considered resolved. Since one resolved element past an unresolved element cannot be counted, 5-1 is the correct reading.

FIGURE B-3

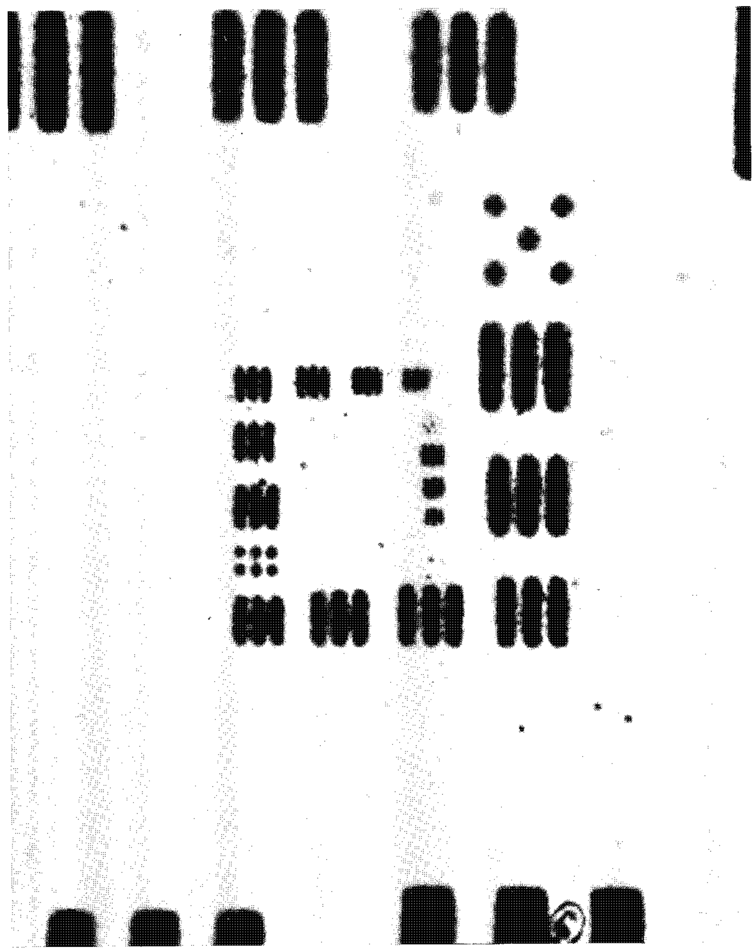
IRARS
TRIBAR RESOLUTION STANDARD

ASA 1966 TARGET

RANGE: 6-6 TO 7-1 FINAL READING: 6-6

FIGURE B-4

IRARS
TRIBAR RESOLUTION STANDARD



ASA 1966 TARGET

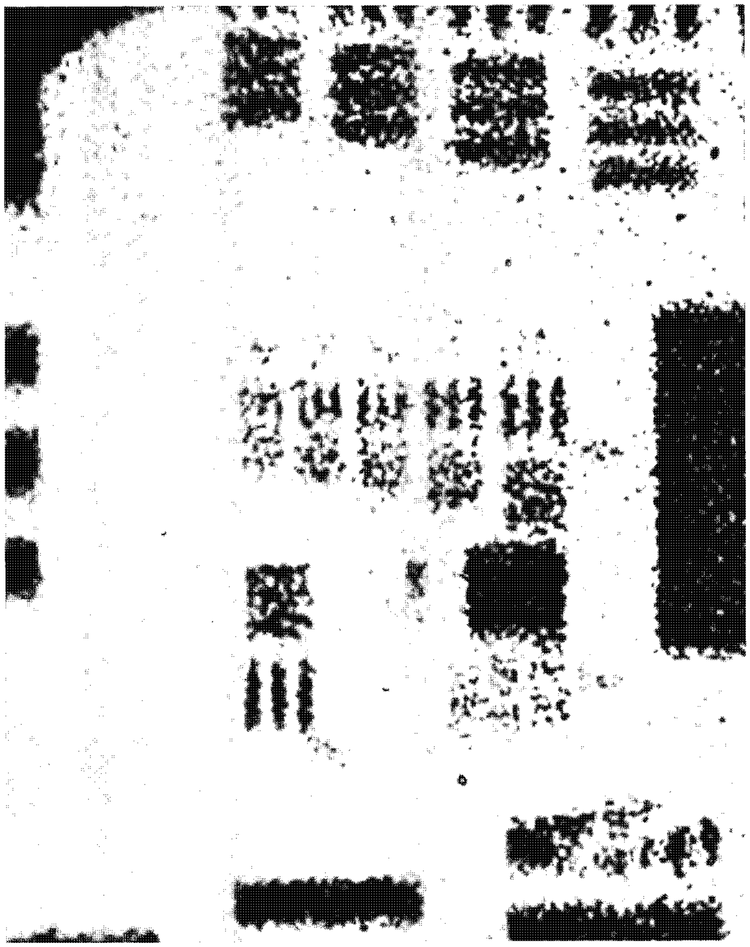
RANGE: 7-2 TO 7-3 FINAL READING: 7-3

NOTE: Element 6-6 is not resolved, however, at least two elements beyond 6-6 are, so the higher reading is acceptable. The last element in the target is 7-3. Higher resolution readings might have been possible if not limited by the target.

FIGURE B-5

BYE 15313-73

IRARS
TRIBAR RESOLUTION STANDARD



USAF 1951 TARGET

RANGE: H -1-5 TO -1-6 FINAL READING: H -1-5

V N/A V O-5

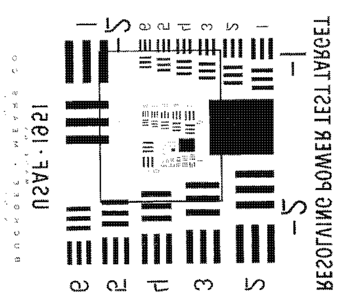
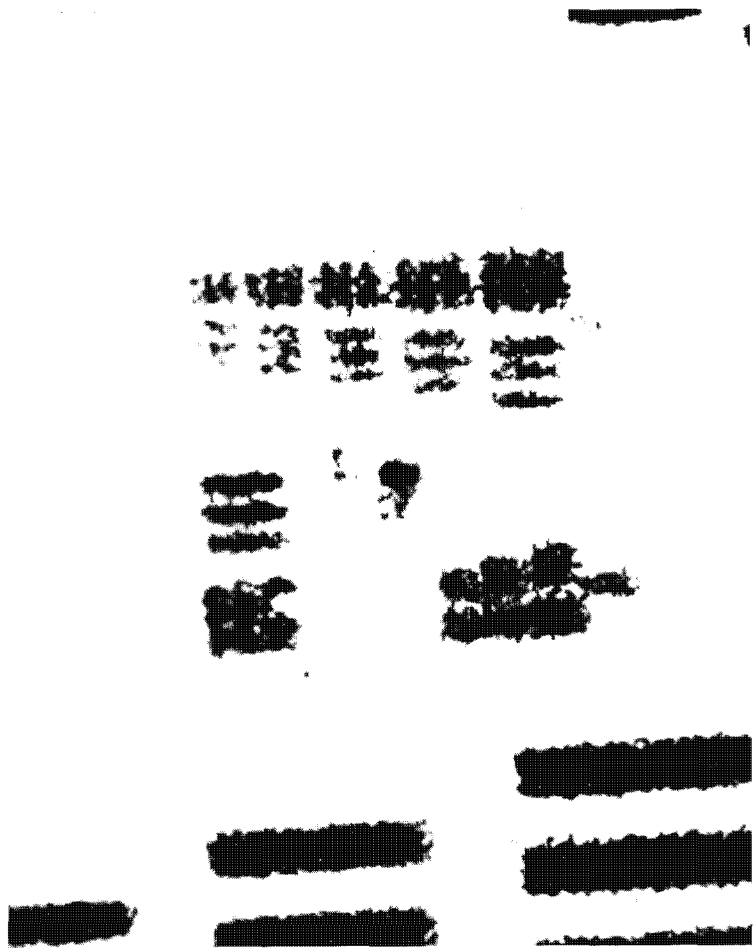


FIGURE B-6 BYE 15313-73

IRARS
TRIBAR RESOLUTION STANDARD



PRINTER STANDARDIZATION MASTER TARGET

RANGE: H 8-4 TO 8-6 FINAL READING: H 8-5
V 8-4 TO 8-6 V 8-5

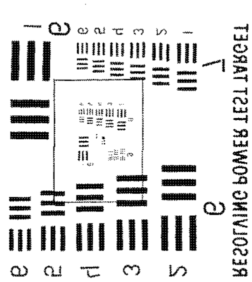
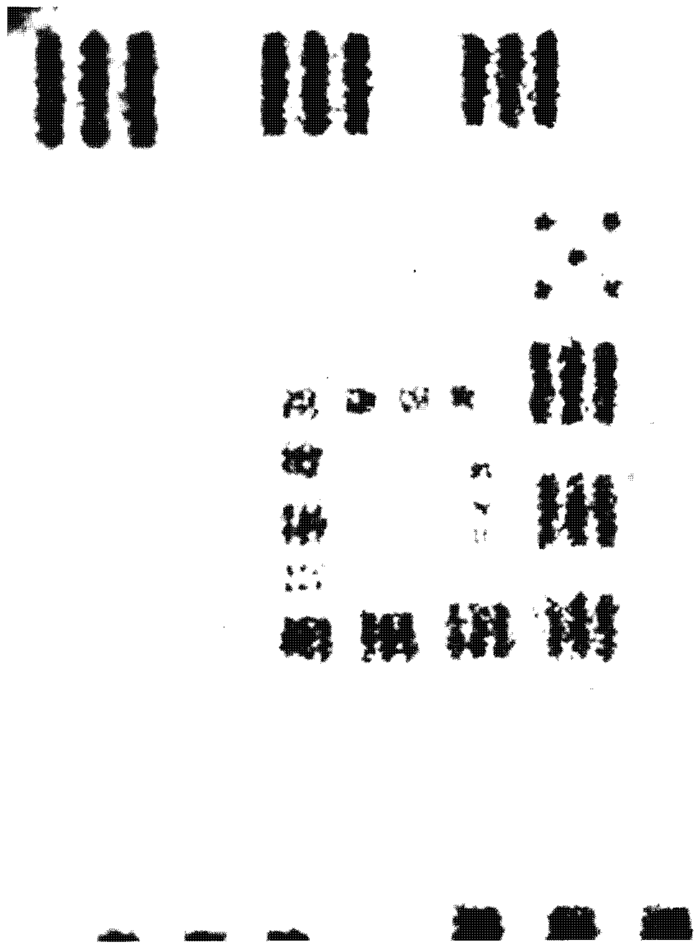


FIGURE B-7

IRARS
TRIBAR RESOLUTION STANDARD



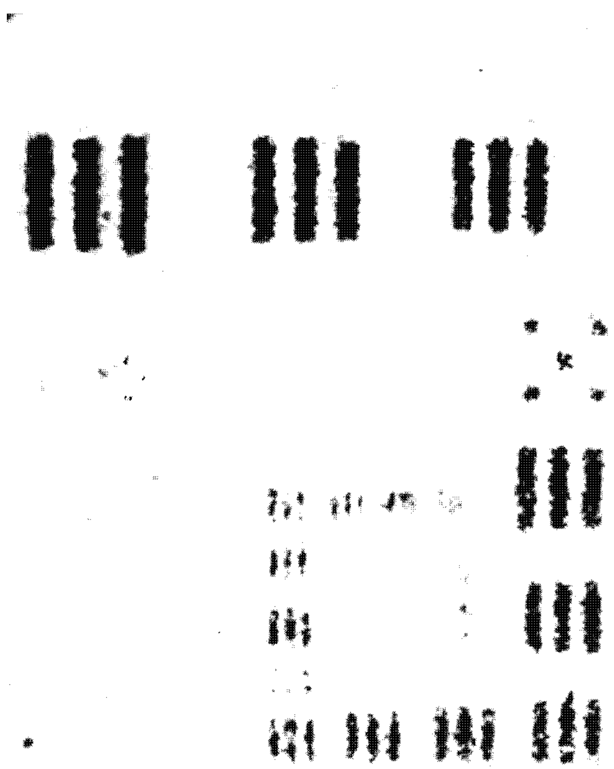
ASA 1966 TARGET

RANGE: 5-5 TO 6-1 FINAL READING: 5-5

NOTE: Elements 5-5 and 6-1 are resolved, however, Element 5-6 is not resolved.

FIGURE B-8

IRARS
TRIBAR RESOLUTION STANDARD



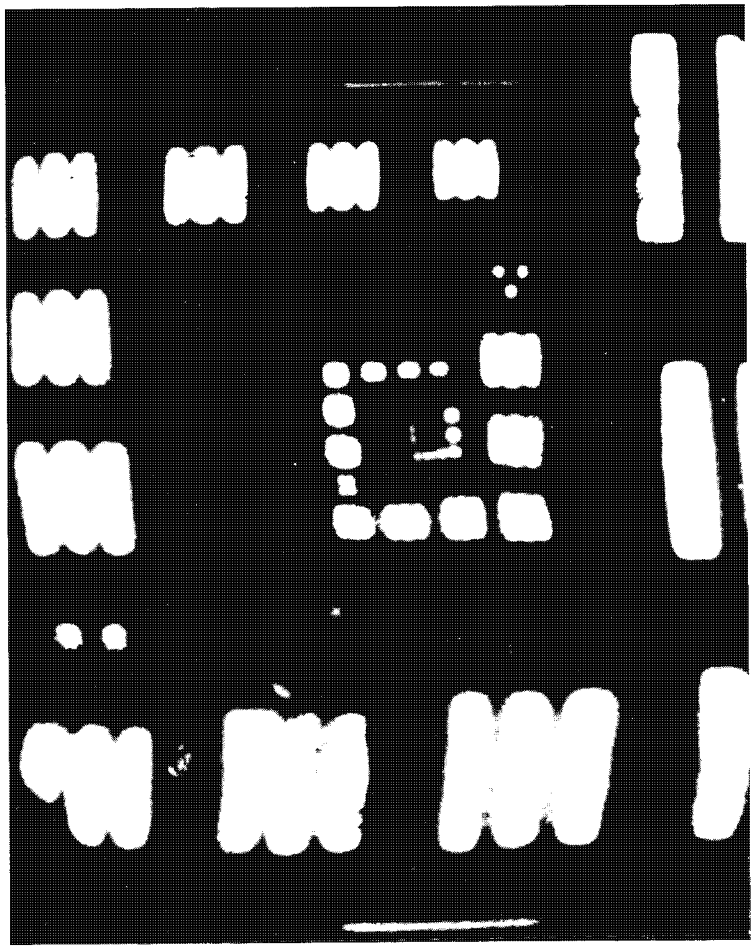
ASA 1966 TARGET

RANGE: 6-2 TO 6-4 FINAL READING: 6-4

NOTE: Elements 6-2 and 6-4 are resolved. With reasonable confidence, Element 6-3 is considered resolved.

FIGURE B-9

IRARS
TRIBAR RESOLUTION STANDARD



ASA 1966 TARGET

(Negative Polarity)

RANGE: 1-4 TO 2-6 FINAL READING: 2-3

NOTE: Element 1-6 was vignetted by the equipment, but is resolved. Elements 2-2 and 2-3 are resolved, whereas 2-1 is not. Elements 2-4, 2-5, and 2-6 are not considered resolved; although the ends of the bars can be distinguished, there must be a separation in the middle of the bars.

FIGURE B-10

IRARS
TRIBAR RESOLUTION STANDARD

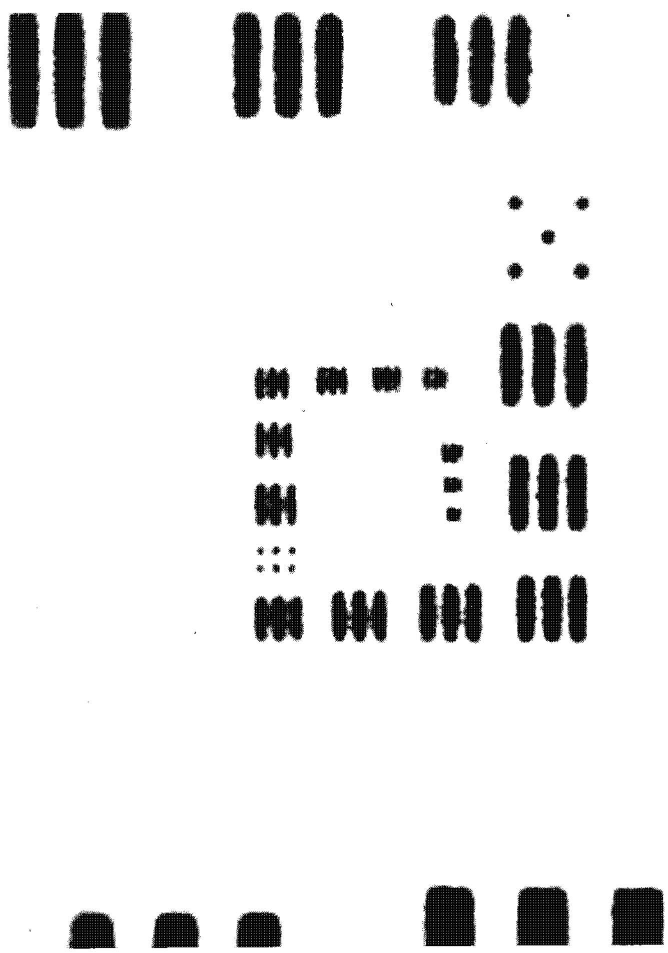
ASA 1966 TARGET

RANGE: 3-5 TO 4-1 FINAL READING: 4-1

NOTE: Elements 3-5 and 4-1 are resolved. With reasonable confidence, Element 3-6 is considered resolved.

FIGURE B-11

IRARS
TRIBAR RESOLUTION STANDARD



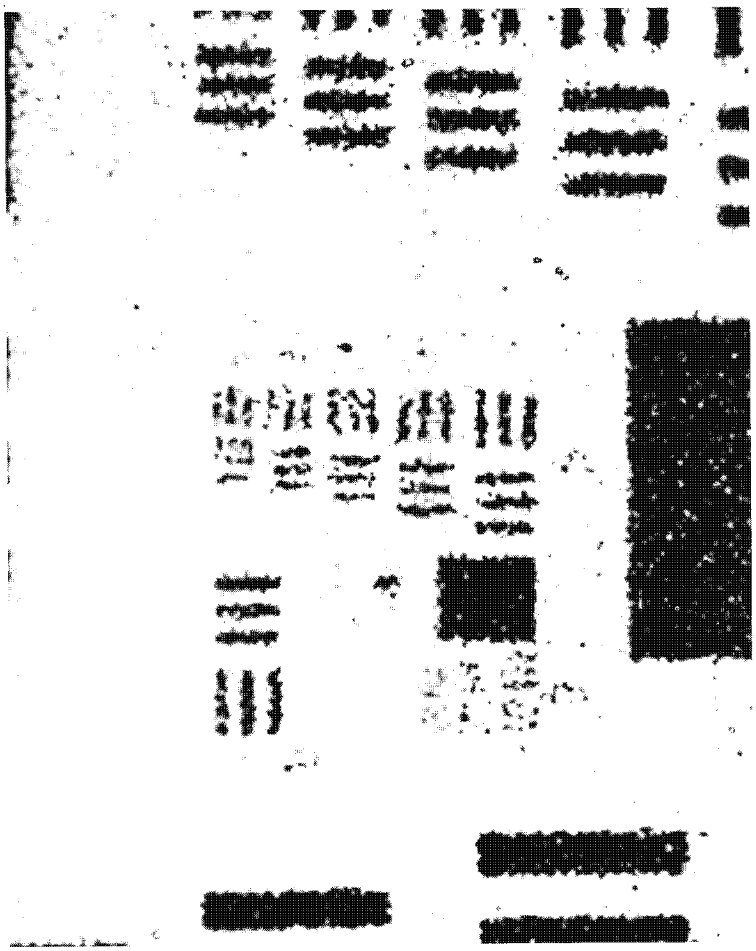
ASA 1966 TARGET

RANGE: 6-5 TO 7-2 FINAL READING: 6-6

NOTE: Element 6-6 is considered resolved but 7-1 is not.

FIGURE B-12

IRARS
TRIBAR RESOLUTION STANDARD



USAF 1951 TARGET

RANGE: H 0-5 TO 1-1 FINAL READING: H 1-1

V N/A V 0-6

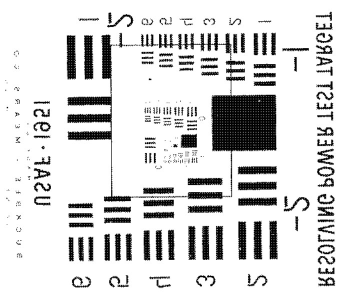
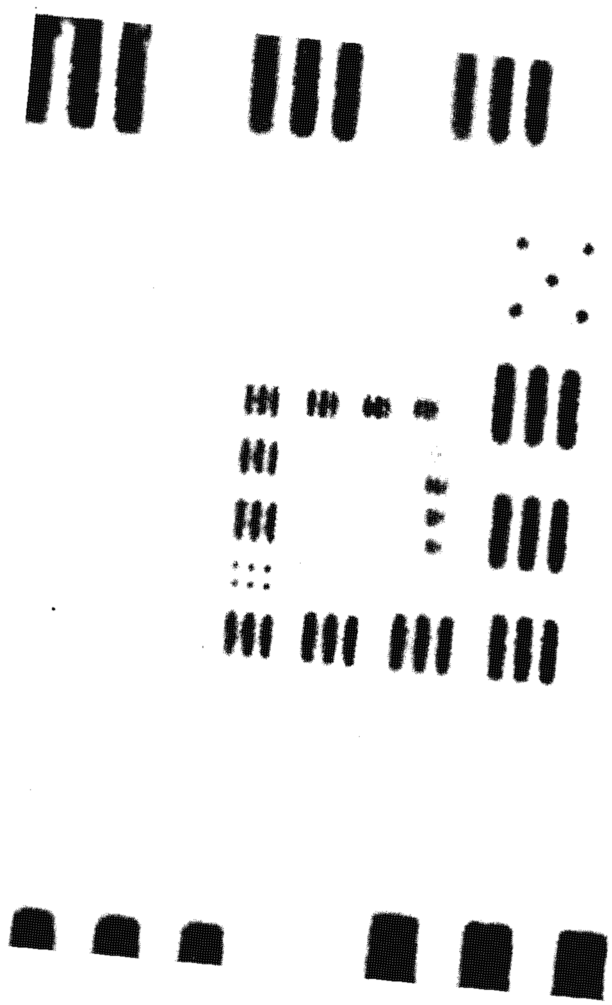


FIGURE B-13

IRARS
TRIBAR RESOLUTION STANDARD



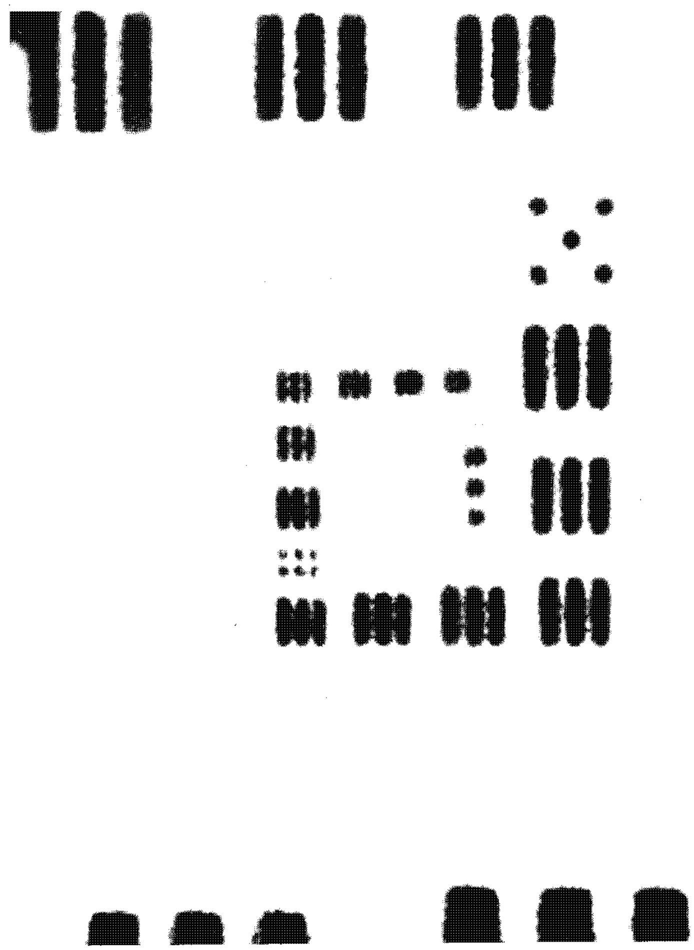
ASA 1966 TARGET

RANGE: N/A

FINAL READING: 7-2

FIGURE B-14

IRARS
TRIBAR RESOLUTION STANDARD



ASA 1966 TARGET

RANGE: 6-4 TO 6-6 FINAL READING: 6-5

FIGURE B-15

APPENDIX C

QUALITY CONTROL MEASURES

C.1 INITIAL STANDARDIZATION AND CERTIFICATION GUIDELINES

A meaningful interchange of resolution data within the reconnaissance community requires that the resolution readers of each participating organization perform tribar reading in accordance with this standard. There are two specific aims of resolution reading standardization. The first is to assure that the reader is not biased too high or too low as determined from his average over a large number of readings compared with the reading community standard. The second aim is to assure that the reader is consistent in his application of the reading standard. The two aims are addressed by calculating a mean value and some measure of dispersion for an individual's reading performance.

Certification of resolution readers will be determined as follows:

A. A reader will be given the training course as prescribed by the Standing Committee.

B. The reader will be tested for certification by reading the standard target set established for this purpose. Cross-track and in-track readings will be treated as separate sets of data and will not be aggregated in the statistical analysis of results.

C. The error between the individual's reading of each tribar target and the standard reading established for that target will be calculated. The mean and standard deviation of this set of errors will be calculated. In the course of computation, the reading errors will be converted into percent error values. NOTE: This approach is consistent with the fact that a constant percent difference in spatial frequency exists between adjacent tribar target elements. Therefore, the absolute resolution difference between elements varies geometrically. For example, with a $6\sqrt{2}$ progression, the constant percent difference in resolution value between adjacent elements is 12 percent.

C.2 READER CERTIFICATION CRITERIA

C.2.1 Background

When the resolution reader training and certification program was initiated, the training set (TRITS) and testing set (MTRITS) were established as "truth." Interim certification criteria were set based on past experience in the resolution reading community and a number of readings made by the Standing Committee for training. During the initial six months of the program, approximately ninety resolution readers were tested at eight facilities. The data from these tests was analyzed and the certification criteria re-evaluated.

One of the interim criteria allowed a mean difference of ± 6 percent. Approximately 66% of the resolution readers tested fell within these limits as shown in Figure C-1. In this figure, the reader's mean difference, expressed in percent, is located on the abscissa and the frequency of occurrence is plotted on the ordinate axis. The percentages of readers falling below, within, and above the certification limits are shown above the distribution curve. As expected, most of the readers who fell outside of the limits did so on the minus (low reading) side. Because the IRARS criterion of "reasonable confidence" is more liberal than some of the previous standards, conservative readings reflected the accustomed criteria. It was concluded from this data that the results were acceptable and the criterion of ±6% limits on the mean difference should not be changed.

The other interim criterion required that the 95% confidence interval about the mean be an interval of no more than 6% in width. Again, reading errors were converted into percent errors. The distribution of the first ninety readers is given in Figure C-2. The interval width at a 95% confidence level, expressed in percent, is located on the abscissa and the frequency of occurrence is plotted on the ordinate axis of this figure. The percentage of readers falling above and below the 6% interval width is shown above the distribution curve. Because this criteria was too stringent, a sample of the best readers was studied in an attempt to determine a more reasonable limit. The sample included only those readers meeting the criterion of a mean difference of ±6% in both reading directions. Data from 50 readers was analyzed yielding a mean confidence interval width of 9.46% with a standard deviation of 2.58 percent. Therefore, the Standing Committee set a certification at one standard deviation above the mean or a confidence interval width of approximately 12 percent. Approximately 74% of the readers tested were "certified" under this new limit while only 1.5% would have qualified under the interim criteria.

It was also decided that the standard deviation should be used as a certification criterion of resolution reading rather than a confidence interval width, since the former is independent of the test set sample size.

In summary, the new certification limit is now set at a maximum allowable standard deviation of 16%, which is the standard deviation corresponding to a 12% confidence interval at the 95% confidence level for the MTRITS data (sample size of 30).

C.2.2 Full Certification

A reader will be deemed fully certified if the mean reading error calculated in both directions is no greater than 6% and the standard deviation of the differences is less than 16 percent.

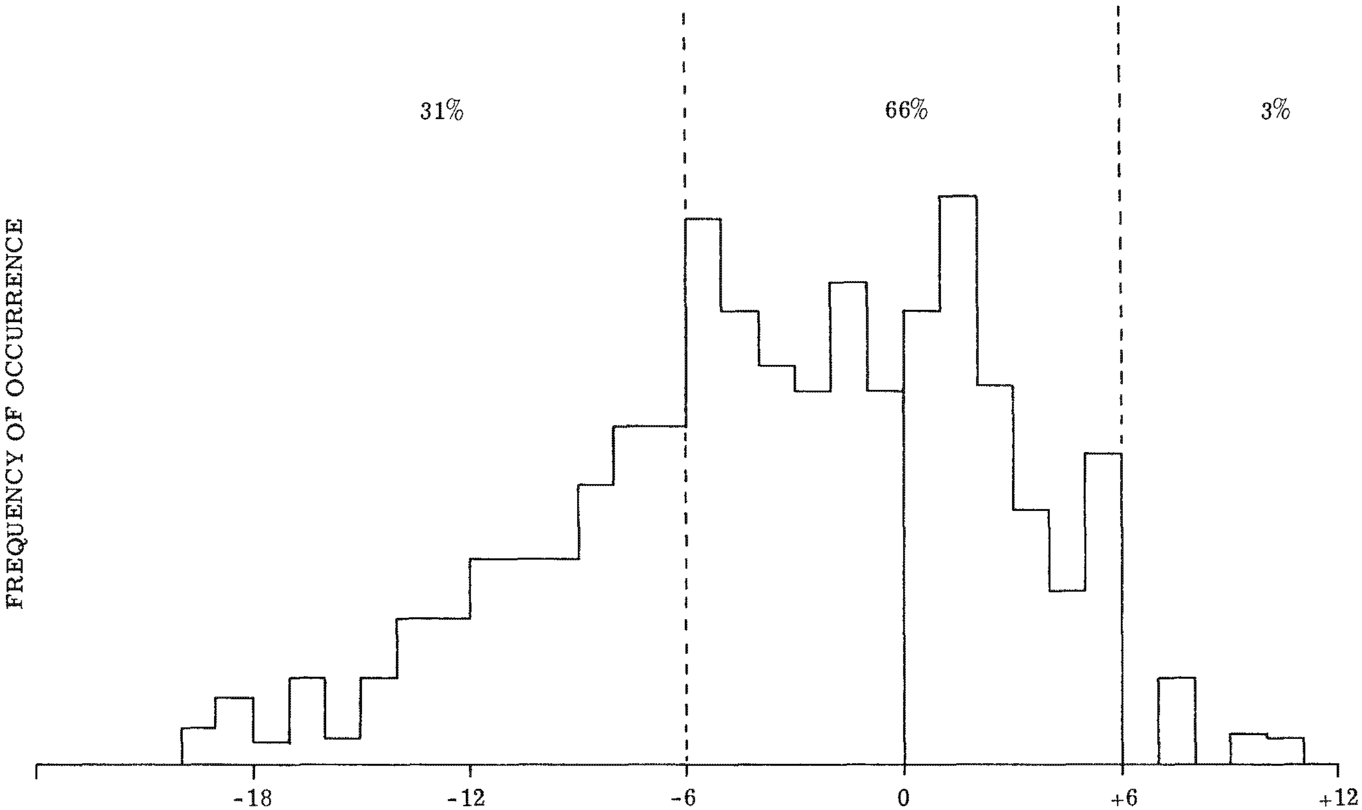
C.2.3 Remedial Training

A reader will undergo remedial training without retesting for certification if his performance does not fully meet the criteria defined in C.2.2 but falls within either of the two following categories:

A. The reader's mean error is greater than 6% but the standard deviation of the differences is less than 16 percent. This indicates that the reader is consistent but his perception of the resolution threshold is different from the standard.

FIGURE C-1

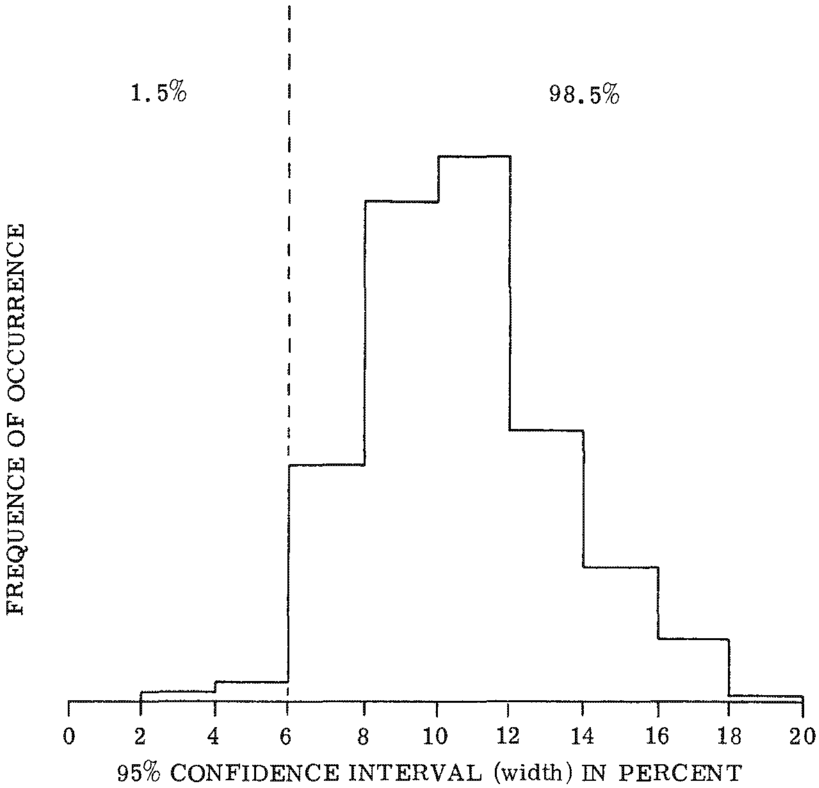
FREQUENCY DISTRIBUTION OF RESOLUTION READING DIFFERENCES



MEAN DIFFERENCE (reading - standard) IN PERCENT

NOTE: The dashed lines indicate established certification limits.

FREQUENCY DISTRIBUTION OF THE WIDTHS AT 95% CONFIDENCE INTERVALS



NOTE: The dashed line indicates the initial certification limit referred to in paragraph C.2.1.

FIGURE C-2

B. The reader's mean error is less than 6% but the standard deviation of the differences is greater than 16 percent. This indicates that the reader generally recognizes the resolution threshold but his performance is not consistent.

C.2.4 Certification Failure

A reader is not certified and must be retrained and retested if analysis of the data reveals that his performance does not meet either certification criterion. A reader must meet these criteria in both the horizontal and vertical (cross-track and in-track) directions to be certified.

The following example illustrates the steps involved in calculation of reader performance under this standard:

Assume 30 different images in the test set of a tribar target with a $6\sqrt{2}$ progression. In this progression, an error of one target element equates approximately to a 12% error.

Test Target	Standard	Reading	Error (Δ) (Reading Minus Standard)
1	12	12	0
2	11	11	0
3	10	12	+2
4	15	14	-1
5	14	13	-1
6	12	12	0
7	13	13	0
.	.	.	.
.	.	.	.
.	.	.	.
28	14	12	-2
29	12	13	+1
30	11	10	-1
		$\Sigma_\Delta =$	-22
		Mean Error: $\bar{X}_\Delta = -.7 =$	-8.4%
		Standard Deviation: $\sigma_\Delta = .8 =$	9.6%

This reader's performance shows that he must undergo remedial training before resuming his duties as a resolution reader. Although his standard deviation is acceptable, his mean error exceeds the 6% limit.

C.3 CONTINUING QUALITY CONTROL OF READERS

Continuous quality assurance of readers at the reading facilities is to be maintained through the use of group and individual control and trend charts. Paragraphs C.4 thru C.6 describe the methods for accomplishing this. It is recommended that the performance of a group be continually monitored by the member of the Standing Committee from that facility. This control check can be accomplished by the use of a set of imagery which can be read at intervals as frequently as necessary to insure compliance with the semi-annual qualification testing requirement.

C.4 PROCEDURES FOR CONSTRUCTION OF $\overline{X}$ AND R CHARTS

A. Collect the data using a method such as Form A, see Figure C-3.

B. Using a subgroup size of 4 (four different readers for a group control chart or four different readings of the same target at different times for an individual's control chart), let each sample consist of the average ($\overline{X}$) and range (R) of the four readings.

C. Compute the upper control limit (UCL) for $\overline{X}$, lower control limit (LCL) for $\overline{X}$, and upper control limit for R. The lower control limit for R is zero with a subgroup of size $n < 6$.

D. Compute and plot $\overline{\overline{X}}$ which is the average $\overline{X}$. Compute and plot $\overline{R}$ which is the average R. See Figures C-4 and C-5.

E. List the samples ($\overline{X}$ and R) in order according to time, increasing from left to right, and plot the samples.

FORM A

Reader ____________ Date ____________

Film Type ____________ Time ____________

Microscope No. ____________ Process ____________

	Reader/Readings				
Subgroup	1	2	3	$\overline{X}$	R
1					
2					
3					

$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$ = ________ $\overline{\overline{X}}$ = ________ $\overline{R}$ = ________

$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$ = ________ $A_2 = .729$

$UCL_R = D_4\overline{R}$ = ________ $D_4 = 2.284$

$LCL_R = D_3\overline{R}$ = ________ $D_3 = 0$

FIGURE C-3

NOTE: A_2, D_3, and D_4 are defined for a subgroup of four samples. Refer to Statistics, by Rickmers, page 564.

INDIVIDUAL CONTROL CHART

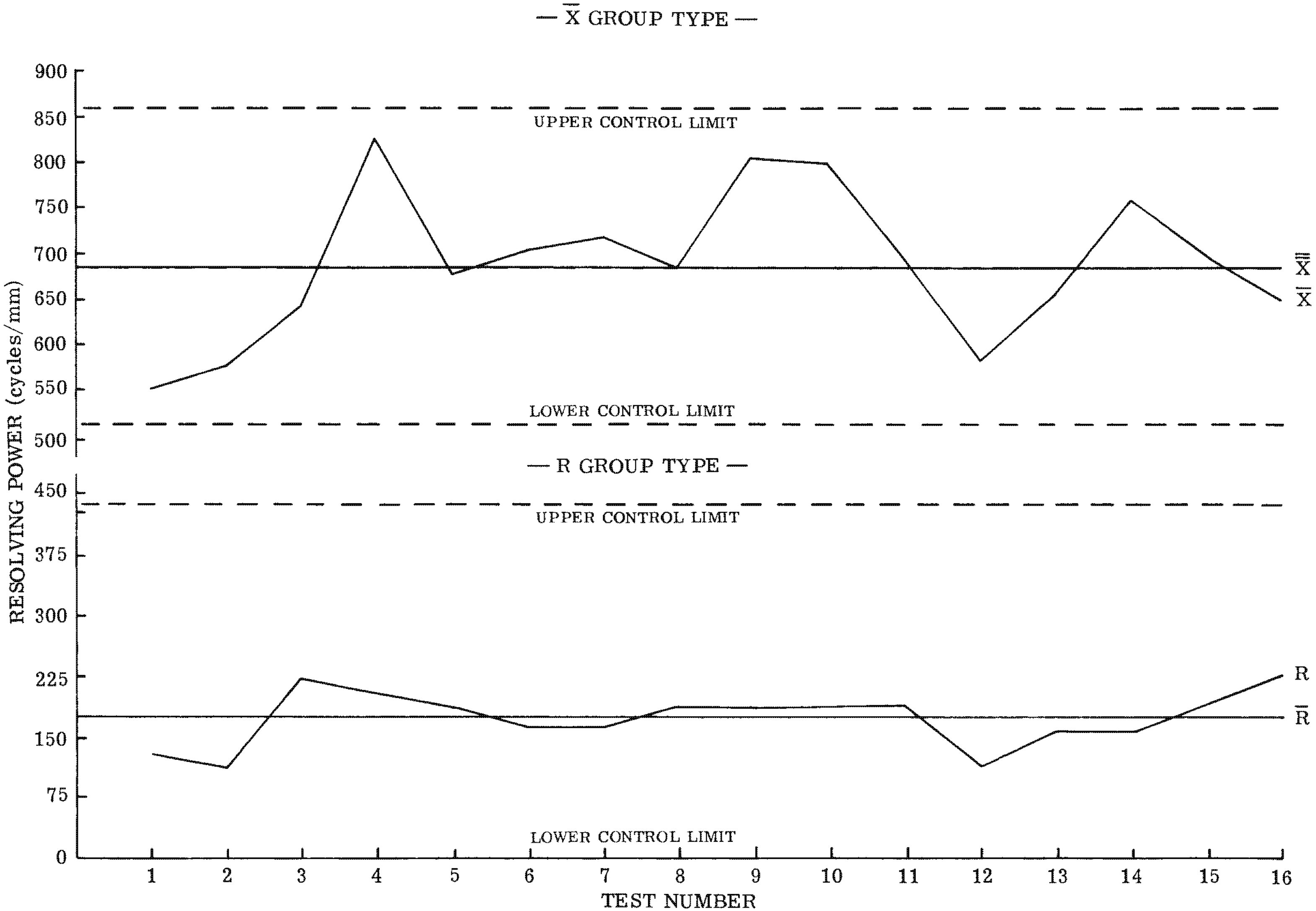
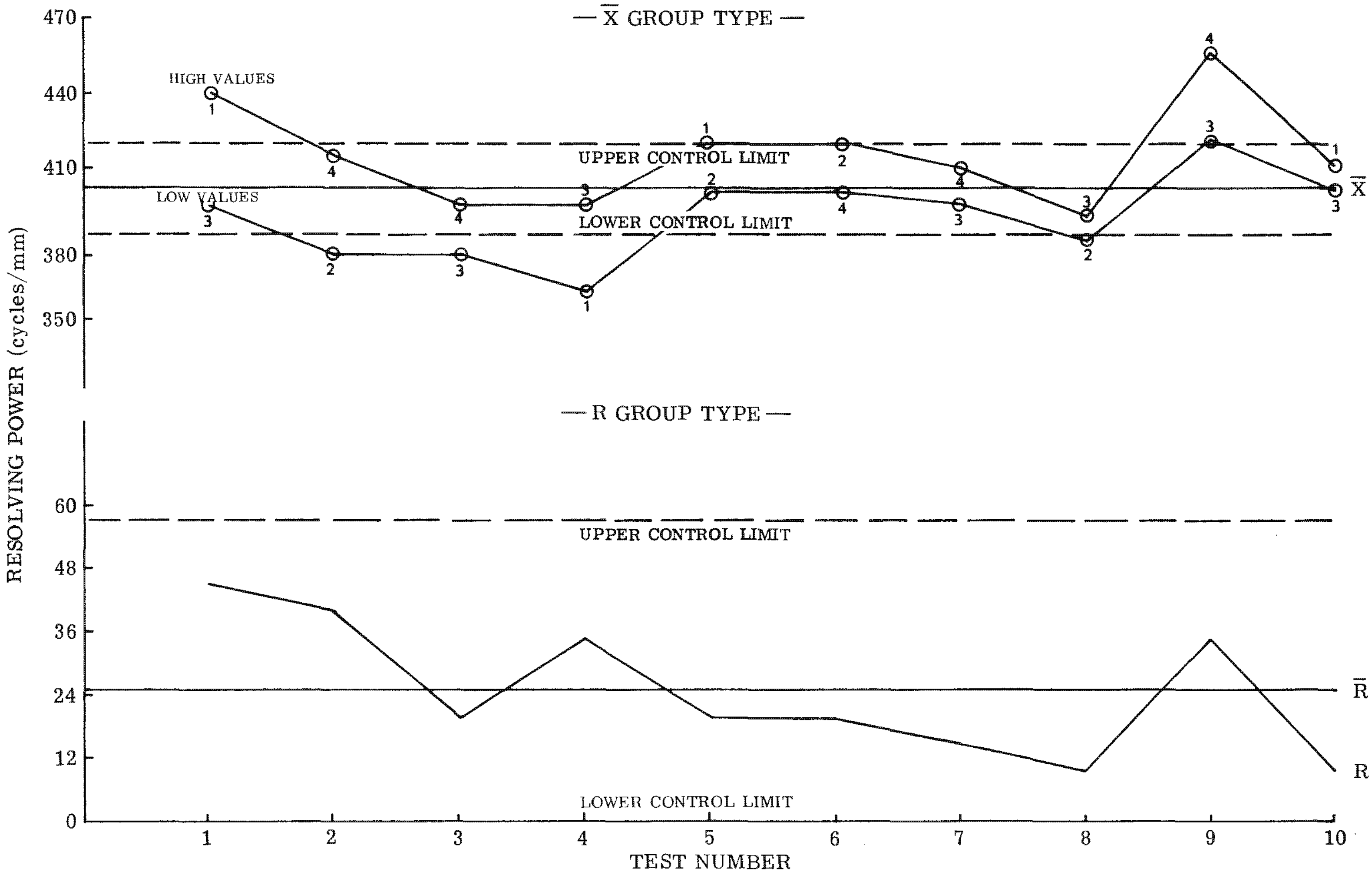


FIGURE C-4

FIGURE C-5

GROUP CONTROL CHART



C.4.1 Rules for Analysis of Control Charts

A system is considered to be out of control when the chart shows any one of the following criteria:

A. Two points in succession are outside the control limits

B. Cycles or other non-random patterns appear in the data.

C. Three out of five points are outside the control limits.

D. Seven successive points are on the same side of the central line.

E. Ten of 11 points are on the same side of the central line.

F. Twelve of 14 successive points are on the same side of the central line.

G. Fourteen of 17 points are on the same side of the central line.

H. Sixteen of 20 points are on the same side of the central line.

If the R chart is out of control and the $\overline{X}$ chart is in control, the readings are inconsistent. If this situation occurs on an individual's chart, then that reader needs retraining. If, on the other hand, the $\overline{X}$ chart is out of control and the R chart is in control, something may be wrong with the instrumentation or there has been a shift in resolution over a long period of time. If the latter is suspected, then construct a trend chart as outlined in paragraph C.5.

C.5 PROCEDURES FOR CONSTRUCTION OF TREND CHARTS

A trend chart can be constructed by the following procedures:

A. Order the subgroups with 1 for the first and n for the last.

B. Code the data. Assign "0" to the median data point and "-1" to the first data point above it, "-2" to the second above it, etc.; then assign "+1" to the first data point below the median, "+2" to the second one below, etc., until all of the data has been coded.

C. Compute the subgroup average $\overline{X}$.

D. Multiply each subgroup average $(\overline{X})$ by the coded subgroup number (h) and sum to get: $\sum_{i=1}^{n} h\overline{X}$.

E. Square the coded subgroups (h^2) and sum: $\sum_{i=1}^{n} h^2$.

F. Compute: $\overline{\overline{X}} = \sum_{i=1}^{n} \overline{X}/n$.

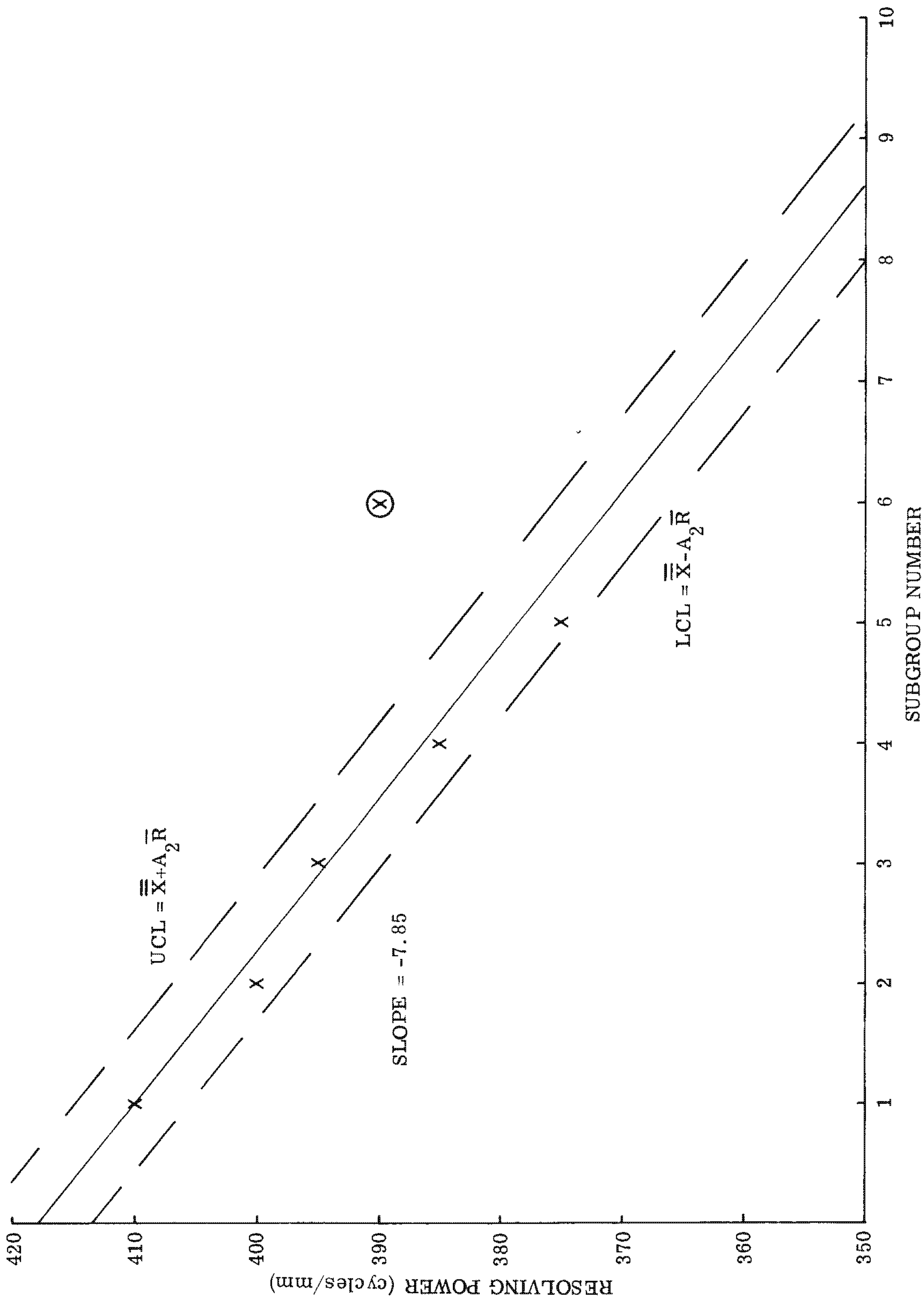
G. The general equation of the trend line is $\overline{X} = a+bh$, where $a = \overline{\overline{X}}$ and $b = \dfrac{\sum_{i=1}^{n} h\overline{X}}{\sum_{i=1}^{n} h^2}$ (when h is defined as above).

H. Compute the limits as in $\overline{X}$ charts, $UCL = \overline{\overline{X}} + A_2\overline{R}$, $LCL = \overline{\overline{X}} - A_2\overline{R}$. The limits are computed for each sample point and the limit lines will be parallel to the trend line.

In the example of a trend chart, Figure C-6, there is general degradation in resolution (downward trend). Subgroup number 6, which is out of control, raises some question as to the variability of the data.

IRARS
TRIBAR RESOLUTION STANDARD

TREND CHART



NOTES: 1. There are four samples in each subgroup.

2. In this case, $A_2\bar{R} = 3.65$.

FIGURE C-6

Therefore, if the next subgroup (number 7) is also out of control, then the data used to construct the chart is suspect.

C.6 STATISTICAL CONTROL REQUIREMENTS FOR RESOLUTION READERS (INDIVIDUALS AND GROUPS)

The following paragraphs offer a more thorough understanding and discussion of the utilization of statistical control and trend charts.

C.6.1 Rules for Construction of $\overline{X}$ Charts

The purpose of any $\overline{X}$ chart is to monitor a level. In order to obtain meaningful statistics for a process, one must employ the following rules:

A. All data used must be consecutively ordered according to the time interval within which it occurred. For example, in measuring the reader variability of one reader in a group of readers, it would be futile to order the resolution from the highest to lowest value before plotting because no meaningful information would be obtained.

B. A "rational"[1] subgroup size must be selected that best conforms to the particular situation at hand so that one obtains maximum information with a minimum sample size. A subgroup size of 3 or 4 is best when one is measuring between rather than within group variability; the use of a larger subgroup size becomes inefficient. On the other hand, if too small a subgroup size is selected, then one runs the risk of rejecting a good reader, or readers, because the variability of the individual measurement will always be greater than the variability of the averages. Hence, a much greater number of samples will be outside the control limits and the reader might be scheduled for retraining when none is needed.

C.6.2 Rules for Construction of Range (R) Charts

The rules for R charts are the same as for the $\overline{X}$ chart. The reason the R chart is constructed is to monitor the dispersion of the data, i.e., the variability. A sigma (σ) chart will serve the same purpose but loses its sensitivity as the subgroup size decreases.

C.6.3 Data Collection

In order to efficiently collect data for the construction of the $\overline{X}$ chart, and to minimize the transposition errors inherent in the measurement/collection/analysis cycle, the development of some form to record the data is suggested. An example of such a form is given in Figure C-3.

C.6.4 Temporary Limits

Since the collecting and recording of measurements very often cause readers to be more conscientious, it is suggested that at least 20-25 subgroups be used to determine the control limits (acceptance/retrain limits) for the $\overline{X}$ and R charts.

However, if neither money nor time permits gathering data from 20-25 subgroups, then temporary limits can be calculated that give some idea as to the level and variability of the system. The procedure is:

[1]E. Grant discusses the rationale of selecting the subgroup sizes in Statistical Quality Control, McGraw Hill, 1971.

First compute the average range ($\overline{R}$): $\overline{R} = \sum_{i=1}^{n} R/n$

where: R = Range

n = Number of subgroups

The control limits for the range chart are:

$$UCL_R = D_4\overline{R}$$

$$LCL_R = D_3\overline{R}$$

The control limits for the $\overline{X}$ chart are:

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$$

The average range ($\overline{R}$) and average $\overline{X}$ value ($\overline{\overline{X}}$) should be graphically depicted by a solid line; the upper and lower control limits for both charts should be indicated by dashed lines at the appropriate levels and labeled UCL and LCL, respectively.

If the process has been in control with both the $\overline{X}$ and R charts, or if the group size used were greater than 20, then the limits may be considered to be "permanent." This doesn't mean that they will never change, but that they can be used to evaluate future data of the same system. Since there is nothing sacred about limits, they may have to be revised from time-to-time according to process changes, reader training, reader proficiency, etc. It is suggested that some periodic review (monthly, every quarter, etc.) of the limits be undertaken to insure monitoring/analysis of the data.

C.6.5 Analysis of Control Charts

A point to keep in mind whenever evaluating a control chart is that an $\overline{X}$ or R chart can indicate when something has gone wrong with the process but can not isolate/identify what the specific problem is. This must be answered by the analyst who is evaluating the problem.

A process is out of control whenever the control chart shows:

A. Seven successive points are on the same side of the central line.

B. Ten of 11 successive points are on the same side of the central line.

C. Twelve of 14 successive points are on the same side of the central line.

D. Fourteen of 17 successive points are on the same side of the central line.

E. Sixteen of 20 successive points are on the same side of the central line.[2]

F. Two points in succession are outside the control limits.

G. Cycles or other non-random patterns appear in the data.

NOTE: These rules apply equally to $\overline{X}$ and R charts.

C.6.6 Group Control Charts

In order to determine whether the resolution reader's group level or dispersion has changed, the individual's resolution values are averaged for the $\overline{X}$ chart; while for the R chart the minimum range is subtracted from the maximum range (so that one is actually plotting the range of the ranges). In both cases, the subgroup size is equal to the number of readers used in the test.[3]

If additional information is of interest, e.g., the highest reader, most inconsistent reader, etc., then another type of group control chart is used. The highest and lowest values of the group are plotted on the $\overline{X}$ chart and the range within the group is used for the R chart. For example, if there are four readers who read on ten different days, then the data would be tabulated as follows:

	Reader			
Day	1	2	3	4
1	440	410	400	395
2	385	375	395	415
3	390	380	375	395
4	365	390	395	370
5	420	400	410	405
6	415	420	410	400
7	400	405	395	410
8	385	380	390	385
9	450	450	420	455
10	410	405	400	405

[2] S. W. Roberts, "Properties of Control Chart Zone Tests", Bell System, Tech. Journal, Vol. 37, pp. 83-114, January 1958.

[3] For variable subgroup sizes, see Grant, Statistical Quality Control, McGraw Hill, pp. 174-177, Kingport, 1971.

The plotted values for the highest level for the 10 days would be: 440, 415, 395, 395, 420, 420, 410, 390, 455, and 410; while the lowest would be 395, 375, 375, 365, 400, 400, 395, 380, 420, and 400. All the plotted points for the low values would be connected to the low values and the high to the high values. Above each low and high point would be placed the reader's number (1, 2, 3, etc.) so that the point could be identified to that particular reader. The average, range, upper control limits and lower control limits would be computed as previously discussed, and the rules for out of control points would apply. This type of chart makes it very evident whether there is a bad reader in the group. For an example of a group type of $\overline{X}$ and R chart, see Figure C-5.

C.6.7 Statistical Trend Charts for Resolution Data

The following are two situations where the trend chart could be used:

A. The same group of readers has been reading resolution for a sustained period of time, they feel or become more proficient and their reading level may increase. Unless one is careful, such an increase may be attributed to an improvement in the process or product when in actual fact none has been obtained.

B. Readers expect an improvement or change in the process or product. If they expect an improvement in resolutions, they may tend to read high. Conversely, if they expect a poorer performance, then they may tend to read low.

C.6.8 Construction of a Trend Chart

A precaution that should be used in the collection of data for the construction of a trend line and accompanying limits is to keep the horizontal increments (time interval) equally spaced. This enables one to obtain a good least square analysis of the trend line. On the conventional $\overline{X}$ chart, the center line is horizontal; the center line on a trend chart will be a sloping line which is described by the following formula:

$$\overline{X} = a+bh$$

where:

h = Subgroup number

b = Slope of the line

a is the value of $\overline{X}$ when h = 0

The simplest case is illustrated below where there are an odd number of observed values with the origin of the horizontal axis taken as the midpoint of the axis (the 0 value of h is assumed to be the middle subgroup).

Under these conditions, $a = \bar{\bar{X}}$, $b = \frac{\sum_{i=1}^{n} h\bar{X}}{\sum_{i=1}^{n} h^2}$.

Subgroup	Revised Subgroup	Subgroup Average ($\bar{X}$)	$h\bar{X}$	h^2
1	-3	410	-1230	9
2	-2	400	-800	4
3	-1	395	-395	1
4	0	385	-	-
5	1	375	375	1
6	2	390	780	4
7	3	350	1050	9

$$\frac{\sum_{i=1}^{n} h\bar{X}}{\sum_{i=1}^{n} h^2} = \frac{-220}{28} = b = -7.86$$

$$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{n} = \frac{2705}{7} = 386.4$$

$$\bar{X} = a + bh$$

$$\bar{X} = 386.4 + -7.85h$$

NOTE: This data is plotted in Figure C-6.

APPENDIX C

QUALITY CONTROL MEASURES

C.1 INITIAL STANDARDIZATION AND QUALIFICATION GUIDELINES

A meaningful interchange of resolution data within the NRP community requires that the resolution readers of each participating organization perform tribar reading in accordance with this standard. There are two specific aims of resolution reading standardization. The first is to assure that the reader is not biased too high or too low as determined from his average over a large number of readings compared with the reading community norm. The second aim is to assure that the reader is consistent in his readings or that they can be repeated with similar results. The two aims are each addressed by calculating a mean value and some measure of dispersion for an individual's reading performance.

Qualification for resolution reading will be determined as follows:

A. A reader will be given the training course as prescribed by the Standing Committee.

B. The reader will be tested for qualification by reading one or more of the standard target sets established for this purpose. Cross-track and in-track readings will be treated as separate sets of data and will not be aggregated in the statistical analysis of results.

C. The error between the individual's reading of each tribar target and the standard reading established for that target will be calculated. The mean and standard deviation of this set of errors will be calculated and used to obtain confidence intervals about the mean. In the course of computation, the transformation of reading errors into percent error values serves to normalize the data and to establish standard qualifying criteria.

C.2 READER QUALIFICATION CRITERIA

C.2.1 A reader will be deemed fully qualified if the mean error calculated is no greater than 6% and the 95% confidence interval about the mean error spans no more than 6%.

For example, the reader whose performance is analyzed and plotted in the following graph is fully qualified:

QUALIFIED READER

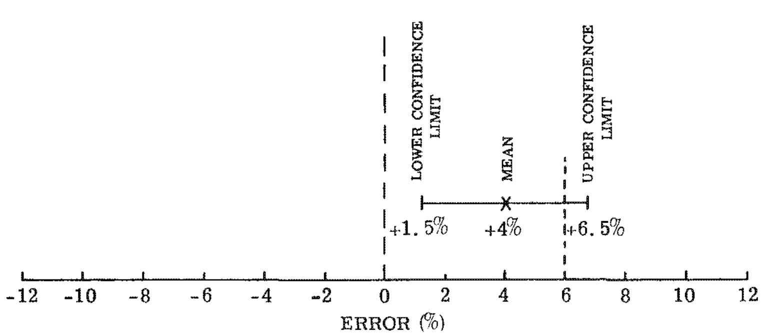


FIGURE C-1

C. 2. 2 A reader will undergo remedial training without retesting for qualification if his performance does not fully meet the criteria defined in C. 2. 1 but falls within either of the two following categories:

A. The reader's mean error is greater than 6% but the 95% confidence interval about his mean error is not greater than 6% and either the lower or upper confidence level falls between -6% and +6% errors. This reader is consistent but his perception is different from the norm. The typical reader in this category would show a performance pattern similar to that presented in Figure C-2.

QUALIFIED READER
(Remedial Training Required)

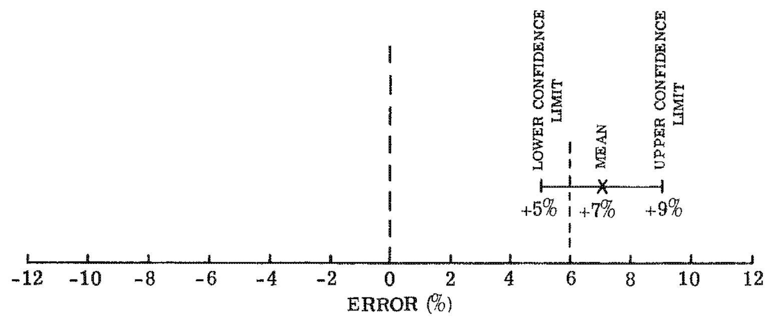


FIGURE C-2

B. The reader's mean error is less than 6% but the 95% confidence interval about his mean error ranges between 6% and 12%. This reader is, on the average, consistent with the norm but his performance is not adequately repeatable, see Figure C-3.

QUALIFIED READER
(Remedial Training Required)

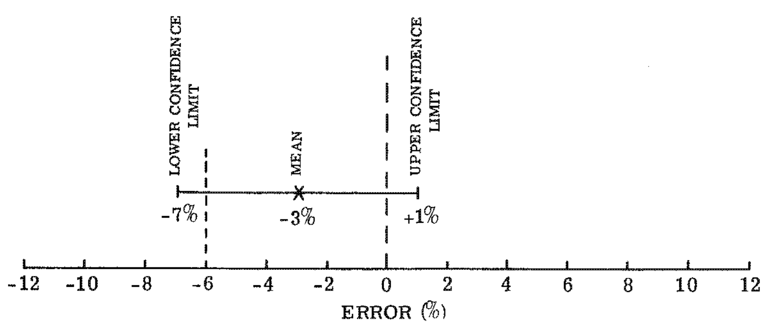


FIGURE C-3

C. 2. 3 A reader is unqualified and must be retrained and retested if analysis of the data reveals that his performance does not meet qualification criteria. An example of an unqualified reader is given in Figure C-4.

UNQUALIFIED READER

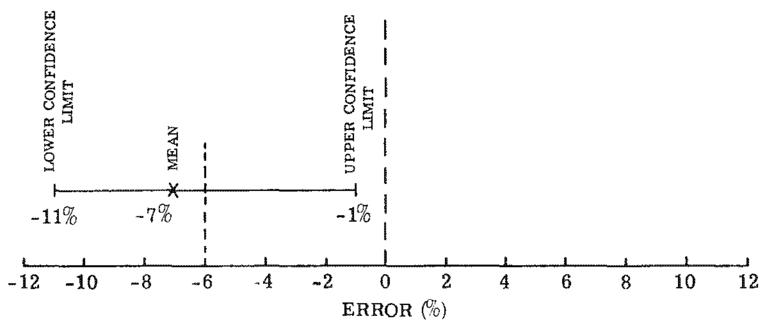


FIGURE C-4

C. 2. 4 The following sample illustrates the steps involved in calculation of reader performance under this standard:

Assume 30 different images in the test set of a tribar target with $\sqrt[6]{2}$ progression. In this progression, an error of one target element equates approximately to a 12% error.

Test Target	Target Element Norm	Readings	Error (Reading Minus Norm)
1	12	12	0
2	11	11	0
3	10	12	+2
4	15	14	-1
5	14	13	-1
6	12	12	0
7	13	13	0
.	.	.	.
.	.	.	.
.	.	.	.
28	14	12	-2
29	12	13	+1
30	11	10	-1
			Σ = -22

$$\text{Mean Error: } \overline{X}_D = -.7 = -8.4\%$$

$$\text{Standard Deviation: } S = .8 = 9.6\%$$

The confidence limits are found from the following formulae:

$$\text{Lower Confidence Limit: } \quad \text{LCfL} = \overline{X}_D - t_{\nu,\alpha} \bullet \left(\frac{S}{\sqrt{n}}\right)$$

$$\text{Upper Confidence Limit: } \quad \text{UCfL} = \overline{X}_D + t_{\nu,\alpha} \bullet \left(\frac{S}{\sqrt{n}}\right)$$

The factor, $t_{\nu,\alpha}$, is obtained from Student's "t" distribution since a true standard deviation for the reader's error is unknown.

For a 95% confidence interval and a sample size of n = 30, $t_{\nu,\alpha}$ is 2.0452.

Thus,

$$\text{LCfL} = -.7 \ -2.0452\left(\frac{.8}{\sqrt{30}}\right) = -1.0 \text{ Target Element}$$

$$\text{UCfL} = -.7 +2.0452\left(\frac{.8}{\sqrt{30}}\right) = -.4 \text{ Target Element}$$

Converting the confidence limits to percent error,

$$\text{LCfL} = -1.0 \times 12\% = -12\%$$

$$\text{UCfL} = -.4 \times 12\% = -4.8\%$$

This reader's performance would show that he is apparently unqualified and must be retrained and retested, see Figure C-5.

UNQUALIFIED READER

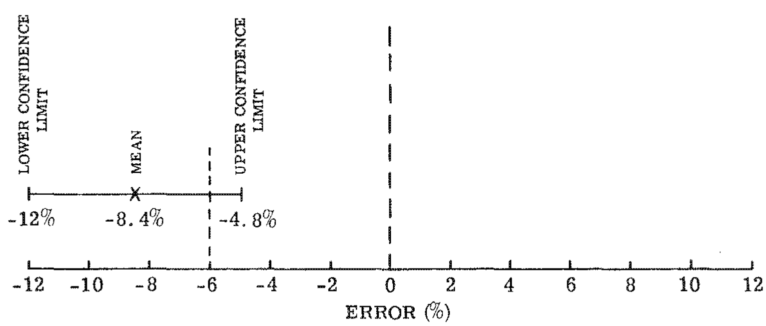


FIGURE C-5

C.3 CONTINUING QUALITY CONTROL OF READERS

Continuous quality assurance of readers at the several reading facilities is to be maintained through the use of group and individual control and trend charts. Paragraphs C.4 thru C.6 describe the methods for accomplishing this. It is recommended that the performance of a group be continually monitored by the member of the Standing Committee from that facility. This control check can be accomplished by the use of a set of imagery which can be read at intervals as frequently as necessary to insure compliance with the semi-annual qualification testing requirement.

C.4 PROCEDURES FOR CONSTRUCTION OF X CHARTS

A. Collect the data using Form A, see Figure C-6.

B. Using a subgroup size of 4 (four different readers for a group control chart or four different readings of the same target at different times for an individual's control chart), average the measurements to obtain the samples.

C. Order the samples according to time (time increasing from left to right).

D. Compute average resolution ($\overline{X}$), of the sample, average range of the resolution of the samples $\overline{R}$, upper control limit (UCL) for $\overline{X}$, lower control limit (LCL) for $\overline{X}$, and upper control limit for range of samples. The lower control limit is zero for a range chart with subgroup size $n < 6$.

E. Plot the $\overline{X}$ and $\overline{R}$ with a solid line and the upper and lower control limits with a broken line, see Figures C-7 and C-8.

FORM A

Reader ______________ Date ______________

Film Type ______________ Time ______________

Microscope No. ______________ Process ______________

Subgroup	Reader 1	2	3	Average $\overline{X}$/Range	$\overline{R}$
1					
2					
3					

$UCL_{\overline{X}} = \overline{X} + A_2\overline{R}$ ___ or $\overline{X}+3$ ______ $n = 4$

$LCL_{\overline{X}} = \overline{X} - A_2\overline{R}$ ___ or $\overline{X}-3$ ______ $A_2 = .729$

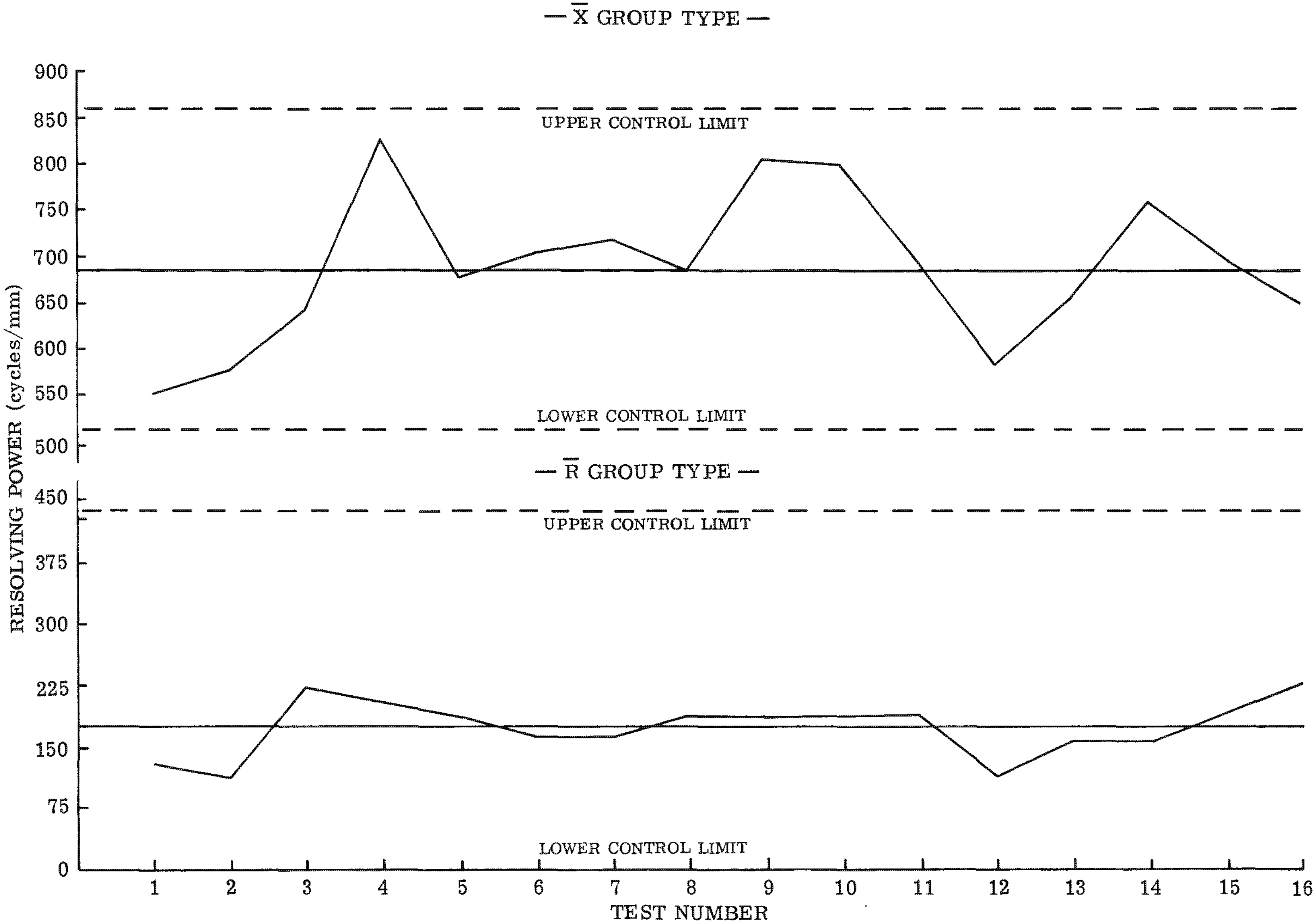
$UCL_{\overline{R}} = D_4\overline{R}$ = ______________ $D_4 = 2.284$

$LCL_{\overline{R}} = D_3\overline{R}$ = ______________ $D_3 = 0$

FIGURE C-6

FIGURE C-7

INDIVIDUAL CONTROL CHART

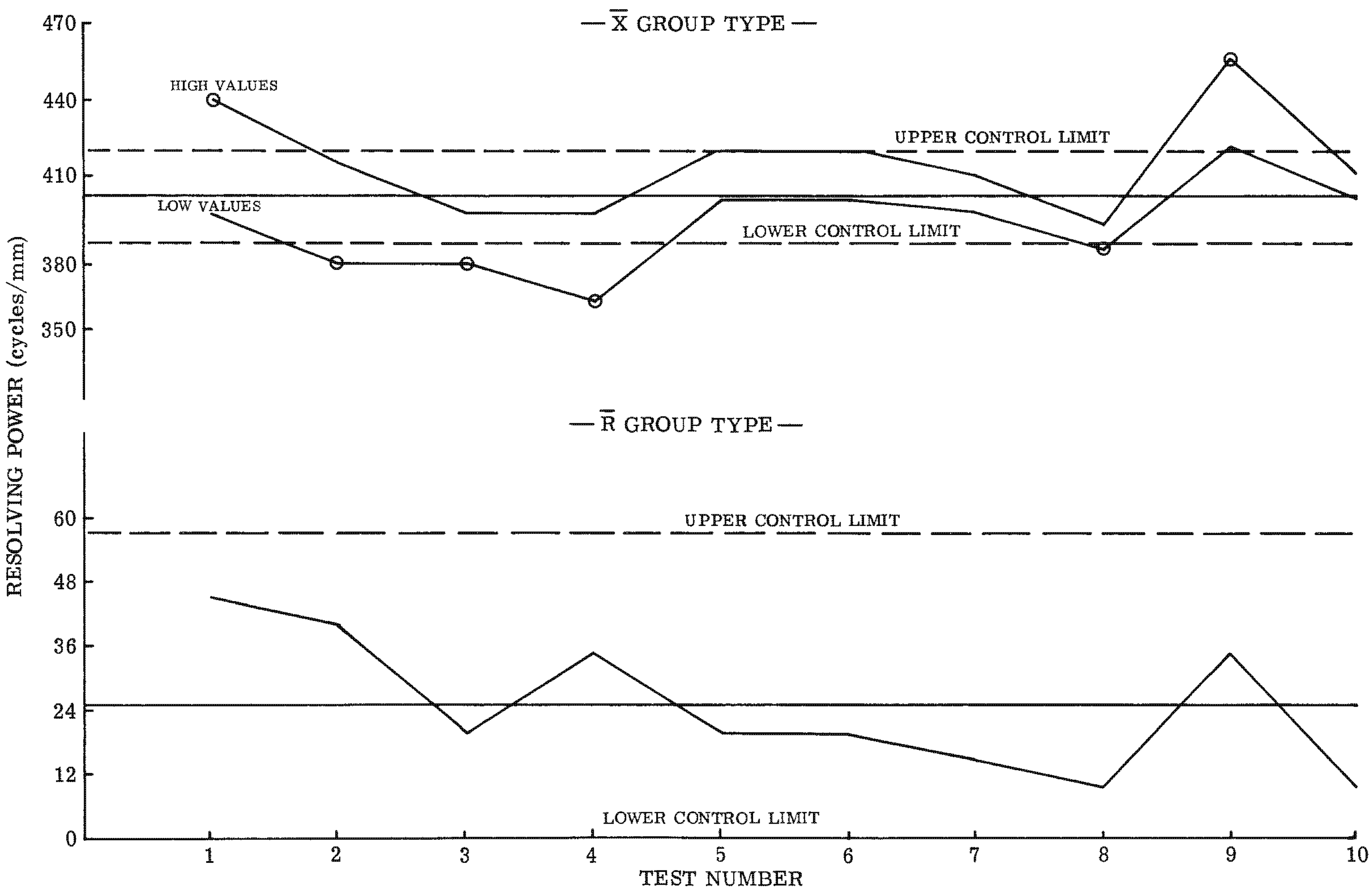


~~TOP SECRET-HEXAGON / GAMBIT~~

Approved for Release: 2018/07/31 C05106617

FIGURE C-8

GROUP CONTROL CHART



C.4.1 Rules for Analysis of Control Charts

A system is considered to be out of control when it meets any one of the following criteria:

A. Two points in succession are outside the control limits.

B. Cycles or other non-random patterns appear in the data.

C. Three out of five points are outside the control limits.

D. Seven successive points are on the same side of the central line.

E. Ten of 11 points are on the same side of the central line.

F. Twelve of 14 successive points are on the same side of the central line.

G. Fourteen of 17 points are on the same side of the central line.

H. Sixteen of 20 points are on the same side of the central line.

If the range chart is out of control and the $\overline{X}$ chart is in control, then this is an indication that someone is reading high. If this situation occurs on an individual's chart, then that reader need retraining. If on the other hand, the $\overline{X}$ is out of control and the range chart is in control, this is an indication that something is wrong with the instrumentation or there has been a shift in resolution levels over a long period of time which was not detected by the R chart. If the latter is suspected, then construct a trend chart as outlined in paragraph C.5.

C.5 PROCEDURES FOR CONSTRUCTION OF TREND CHARTS

A trend chart can be constructed by the following procedures:

A. Order the subgroups with 1 for the first and n for the last.

B. Compute the subgroup average $\overline{X}$.

C. Code the data. Assign zero (0) to the median data point and minus one (-1) to the first data point above it, minus two (-2) to the second above it, etc.; then assign plus one (+1) to the first data point below the median, plus two (+2) to the second one below, etc., until all of the data has been coded.

D. Multiply each subgroup average $(\overline{X})$ by the coded subgroup number (h) and sum to get $\sum_{i=1}^{n} h\overline{X}$.

E. Square the coded subgroups (h^2) and sum them: $\sum_{i=1}^{n} h^2$.

F. Compute $\overline{\overline{X}}$ which equals $\sum_{i=1}^{n} \overline{X}/n$.

G. The general equation of the trend line is $\overline{X} = a+bh$, where $a = \overline{\overline{X}}$ and $b = \dfrac{\Sigma h\overline{X}}{\Sigma h^2}$.

H. Compute the limits as in $\overline{X}$ charts, $UCL = \overline{X} + A_2\overline{R}$, $LCL = \overline{X} - A_2\overline{R}$. The confidence limits will be parallel to the trend line.

In the example of a trend chart, Figure C-9, there is general degradation in resolution (downward trend). Subgroup number 6, which is out of control, raises some question as to the variability of the data.

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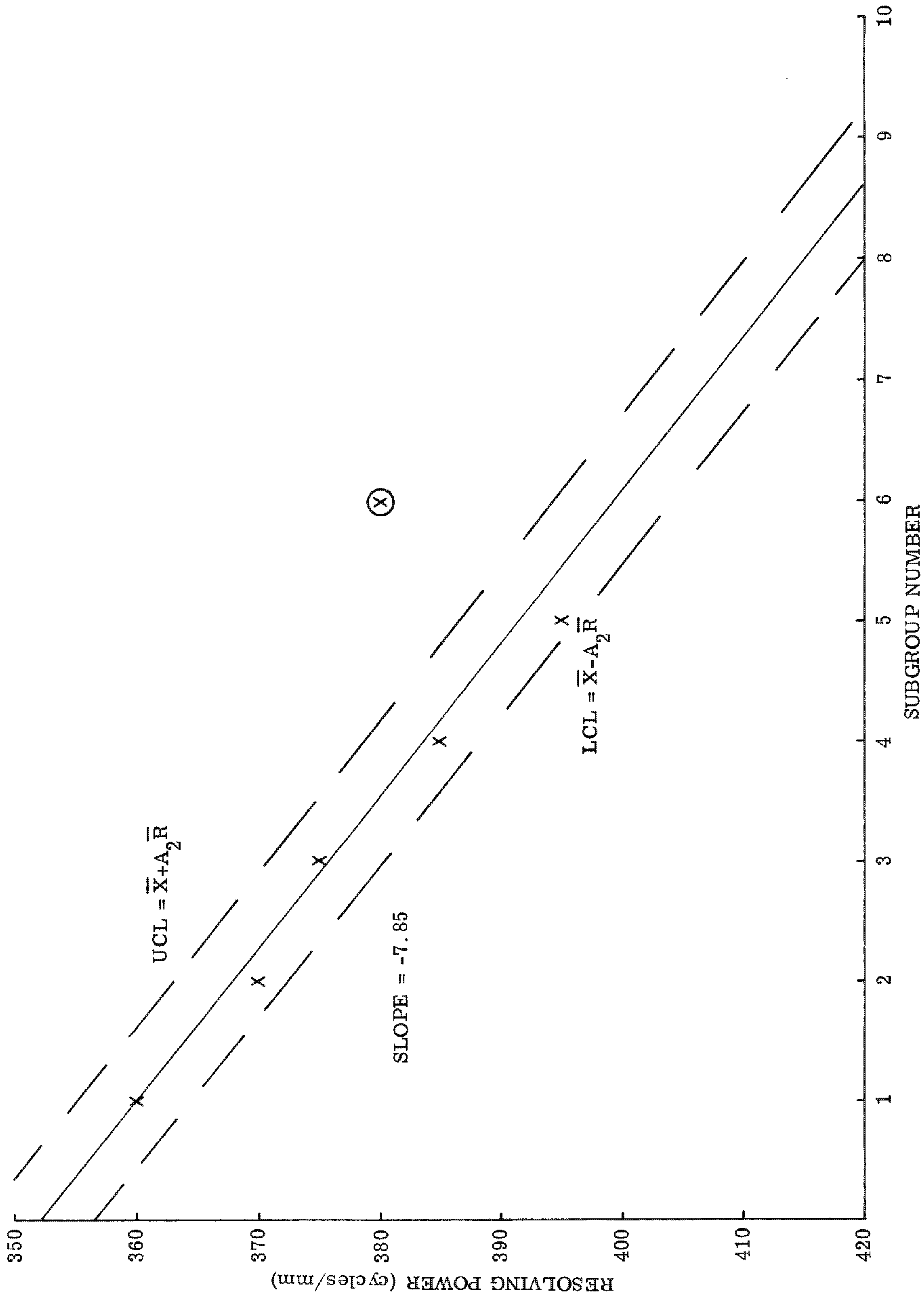
TREND CHART



NOTES: 1. There are four samples in each subgroup.
2. In this case, $A_2\overline{R}$ = 3.65.

FIGURE C-9

Handle via Byeman
Controls Only

Therefore, if the next point (number 7) is also out of control, then the data used to construct the chart is suspect.

C. 6 STATISTICAL CONTROL REQUIREMENTS FOR RESOLUTION READERS (INDIVIDUALS AND GROUPS)

The following paragraphs offer a more thorough understanding and discussion of the utilization of statistical control and trend charts.

C. 6. 1 Rules for Construction of $\overline{X}$ Charts

The purpose of any $\overline{X}$ chart is to monitor a level. In order to obtain meaningful statistics for a process, one must employ the following rules:

A. All data used must be consecutively ordered according to the time interval within which it occurred. For example, in measuring the reader variability of one reader in a group of readers, it would be futile to order the resolution from the highest to lowest value before plotting because no meaningful information would be obtained.

B. A "rational"* subgroup size must be selected that best conforms to the particular situation at hand so that one obtains maximum information with a minimum sample size. A subgroup size of 3 or 4 is best when one is measuring between rather than within group variability; the use of a larger subgroup size becomes inefficient. On the other hand, if too small a subgroup size is selected, then one runs the risk of rejecting a good reader, or readers, because the variability of the individual measurement will always be greater than the variability of the averages. Hence, a much greater number of samples will be outside the control limits and the reader might be scheduled for retraining when none is needed.

C. 6. 2 Rules for Construction of Range (R) Charts

The rules for R charts are the same as for the $\overline{X}$ chart. The reason the R chart is constructed is to monitor the dispersion of the data, i. e. , the variability. A sigma (σ) chart will serve the same purpose but loses its sensitivity as the subgroup size decreases.

C. 6. 3 Data Collection

In order to efficiently collect data for the construction of the $\overline{X}$ chart, and to minimize the transposition errors inherent in the measurement/collection/analysis cycle, the development of some form to record the data is suggested. An example of such a form is given in Figure C-6.

C. 6. 4 Temporary Limits

Since the collecting and recording of measurements very often cause readers to be more conscientious, it is suggested that at least 20-25 subgroups be used to determine the control limits (acceptance/retrain limits) for the $\overline{X}$ and R charts.

However, if neither money nor time permits, then temporary limits can be calculated that give some idea as to the level and variability of the system.

*E. Grant discusses the rationale of selecting the subgroup sizes in Statistical Quality Control, McGraw Hill, 1971.

First compute the average range $(\overline{R})$. $\overline{R} = \sum_{i=1}^{n} R/n$

where: R = Range

n = Number of subgroups

The control limits for the range chart are:

$$UCL_R = D_4\overline{R}$$

$$LCL_R = D_3\overline{R}$$

The control limits for the $\overline{X}$ chart are:

$$LCL_X = -A_2\overline{R}+\overline{X}$$

$$UCL_X = +A_2\overline{R}+\overline{X}$$

The average range $(\overline{R})$ and average value $(\overline{X})$ should be graphically depicted by a solid line; the upper and lower control limits for both charts should be indicated by a dashed line at the appropriate levels and labeled UCL and LCL.

If the process has been in control with both the average and range charts, or if the group size used was greater than 20, then the limits may be considered to be "permanent". This doesn't mean that they will never change, but that they can be used to evaluate future date of the same system. Since there is nothing sacred about limits, they may have to be revised from time-to-time according to process changes, reader training, reader proficiency, etc. It is suggested that some periodic review (monthly, every quarter, etc.) of the limits be undertaken to insure appropriate analysis of the data.

C.6.5 Analysis of Control Charts

A point to keep in mind whenever evaluating a control chart is that an $\overline{X}$ or R chart can indicate when something has gone wrong with the process but it can't isolate/identify what the specific problem is. This must be answered by the analyst who is evaluating this problem.

A process is "out of control" whenever one observes:

A. Seven successive points on the control chart and all are on the same side of the central line.

B. Eleven successive points on the control chart and at least 10 are on the same side of the central line.

C. Fourteen successive points on the control chart and at least 12 are on the same side of the central line.

D. Seventeen successive points on the control chart and at least 14 are on the same side of the central line.

E. Twenty successive points on the control chart and at least 16 are on the same side of the central line.[1]

F. Two points in succession are outside the control limits.

G. Cycles or other non-random patterns appear in the data.

NOTE: These rules apply equally to $\overline{X}$ and R charts.

C.6.6 Group Control Charts

In order to determine whether the resolution reader's group level or dispersion has changed, the individual's resolution values are averaged for the $\overline{X}$ chart; while for the R chart the minimum range is subtracted from the maximum range (so that one is actually plotting the range of the ranges). In both cases, the subgroup size is equal to the number of readers used in the test.[2]

If additional information, i.e., the highest reader, most inconsistent reader within the group, etc., is of interest, then a group control chart is used.

Generally speaking, the highest and lowest values are averages and plotted on the same graph as the range. In this group control chart, the same data used for the individual's charts would be used. For example, if there are four readers who read on ten different days, then the data would be tabulated as follows:

	Reader			
Days	1	2	3	4
1	440	410	400	395
2	385	375	395	415
3	390	380	375	395
4	365	390	395	370
5	420	400	410	405
6	415	420	410	400

[1]S.W. Roberts, "Properties of Control Chart Zone Tests", Bell System, Tech. Journal, Vol. 37, pp. 83-114, January 1958.

[2]For variable subgroup sizes, see Grant, Statistical Quality Control, McGraw Hill, pp. 174-177, Kingport 1971.

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	Reader			
Days	1	2	3	4
7	400	405	395	410
8	385	380	390	385
9	450	450	420	455
10	410	405	400	405

The plotted values for the highest level for the 10 days would be: 440, 415, 395, 395, 420, 420, 410, 455, and 410; while the lowest values would be 395, 375, 375, 360, 400, 400, 395, 380, 420, and 400. All the plotted points for the low values would be connected to the low values and the high to the high values. Above each low and high point would be placed the reader's number (1, 2, 3, or) so that the point could be identified to that particular reader. The average, range, upper control limits and lower control limits would be computed as previously discussed, and the rules for out of control points would apply. This type of chart makes it very evident as can readily be seen from this type of chart, if whether there is a bad reader in the group. For an example of a group type of $\overline{X}$ and R chart, see Figure C-8.

C. 6. 7 Statistical Trend Charts for Resolution Data

Two examples of the use of a trend chart are whenever:

A. The same group of readers has been reading resolution for a sustained period of time, they can become more proficient and their reading level may increase. Unless one is careful, such an increase may be attributed to an improvement in the process/produce when in actual fact none has been obtained.

B. Readers suspect/expect an improvement or change in the process. If their expectancy level is high, then they may tend to read high. Likewise, if their expectancy is low, then they may read low.

C. 6. 8 Construction of a Trend Chart

A precaution that should be used in the collection of data for the construction of a trend line and accompanying limits is to keep the horizontal increments (time interval) equally spaced. This enables one to obtain a good least square analysis of the trend line. On the conventional $\overline{X}$ chart, the center line is horizontal; the center line on a trend chart will be a sloping line which is described by the following

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TRIBAR RESOLUTION STANDARD

formula:

$$\bar{X} = a+bh$$

where:

h = Subgroup number

b = Slope of the line

a is the value of $\bar{\bar{X}}$ when h = 0

The simplest case is illustrated below where there are an odd number of observed values with the origin of the horizontal axis taken as the midpoint of the axis (the 0 value of h is assumed the middle subgroup). Under these conditions, $a = \bar{\bar{X}}$, $b = \dfrac{\Sigma h\bar{X}}{\Sigma h^2}$

Subgroup	Revised Subgroup	Subgroup Average ($\bar{X}$)	$h\bar{X}$	h^2
1	-3	410	-1230	9
2	-2	400	-800	4
3	-1	395	-395	1
4	0	385	-	-
5	1	375	375	1
6	2	390	780	4
7	3	350	1050	9

$$\frac{\Sigma h\bar{X}}{\Sigma h^2} = \frac{-220}{28} = b = -7.86$$

$$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{n} = \frac{2705}{7} = 386.4$$

$$\bar{X} = a + bh$$

$$\bar{X} = 386.4 + -7.85h$$

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APPENDIX D

GLOSSARY

This appendix provides a brief description of those terms which have not been explained in the text.

ACCURACY - Refers to the closeness of a measurement (a reading) with respect to the "true" value, if known, or to some accepted standard value, e.g., a mean.

ABERRATION - Generally, any characteristic which causes deviation of image-forming light rays from an ideal path through an optical system, resulting in image imperfections. Specifically, seven types of optical aberration can be isolated and described using geometrical concepts:

Spherical Aberration - The result of light rays emanating from a common axial point, impacting the lens surface at different distances from the optical axis, without coming to a common focal point on the optical axis, see Figure D-1.

SPHERICAL ABERRATION

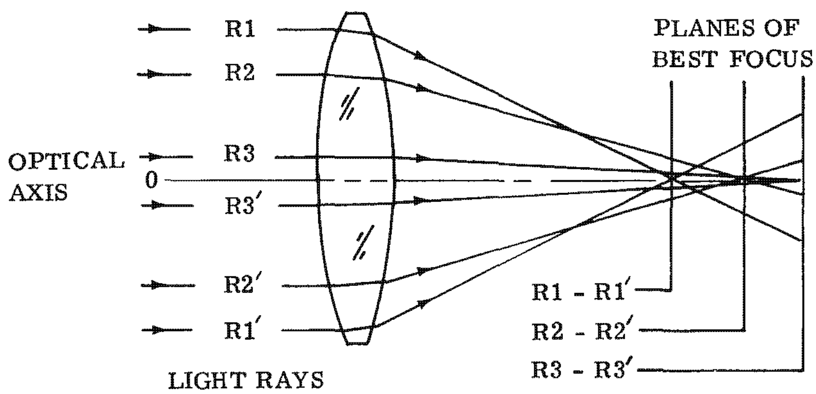

FIGURE D-1

Coma - The result of light rays emanating from an object point off-axis and entering the optics obliquely as a circular bundle of light rays which form a comet-shaped image, see Figure D-2.

COMA

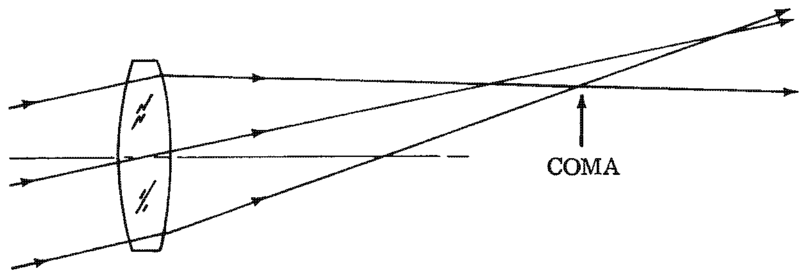

FIGURE D-2

Field Curvature - The result of light rays emanating from an object plane and coming to focus on a curved or non-flat image surface, see Figure D-3.

FIELD CURVATURE

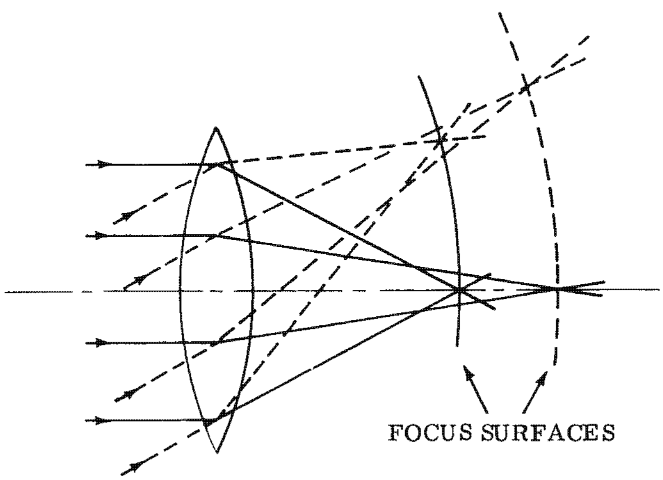

FIGURE D-3

Astigmatism - The result of light rays emanating from a common off-axis point and coming to focus in two different planes of best focus, i.e., one plane radial and the other tangential to the optical axis. This is the basis for the difference between what is referred to as the in-track and cross-track plane of best focus, see Figure D-4.

ASTIGMATISM

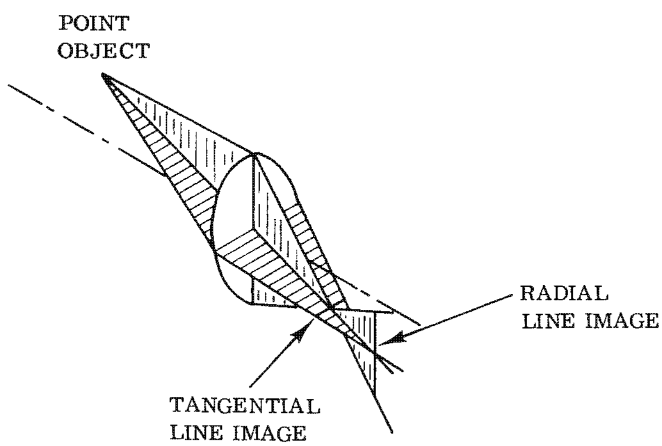

FIGURE D-4

Chromatic Longitudinal Aberration - The result of light rays emanating from a common axial point and coming to focus at different locations along the optical axis as a function of wavelength, i.e., the plane of best focus changes as a function of wavelength, see Figure D-5. Lenses corrected for a red, green, and blue wavelength are referred to as apochromats. Lenses corrected for a blue and green wavelength only are referred to as achromats.

CHROMATIC LONGITUDINAL ABERRATION

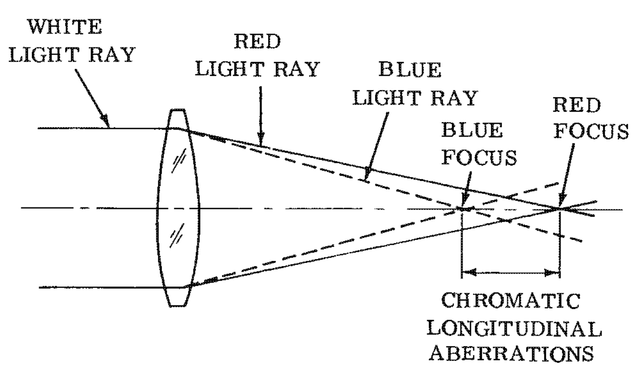

FIGURE D-5

Chromatic Lateral Aberration - The result of light rays emanating from a single point which is imaged at different magnifications as a function of wavelength. That is, the effective focal length of the lens is a function of wavelength, see Figure D-6.

CHROMATIC LATERAL ABERRATION

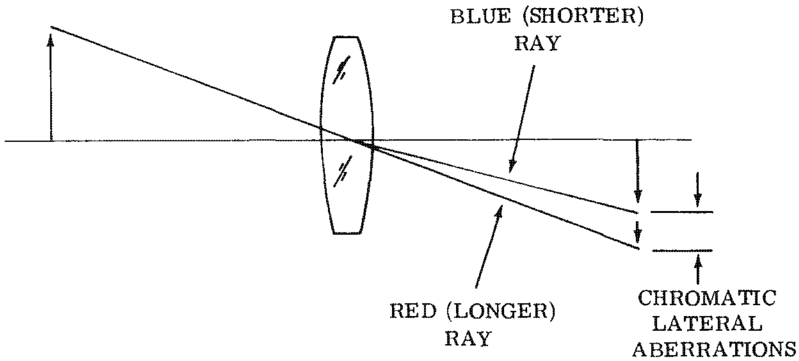

FIGURE D-6

Distortion - The result of light rays emanating from an off-axis point object whose image is displaced from an ideal position without necessarily affecting the image definition, see Figure D-7. A panoramic camera lens distortion is further compounded by a time-dependent scan-generated panoramic distortion.

DISTORTION

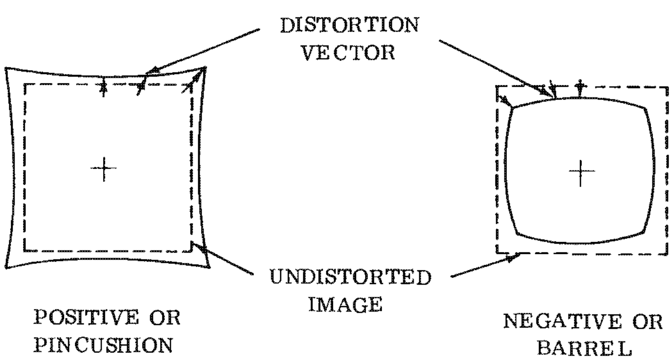

FIGURE D-7

BRIGHTNESS - A term that relates to the human perception of light level or intensity. The quantitative measure of brightness is referred to as luminance. In a normal photographic situation, higher object brightness levels are rendered as higher density levels in the developed (original negative) image.

DENSITY - A measure of the fractional amount of light transmitted through a portion of developed image in a film. Density (D) is defined as the log of reciprocal transmittance (T), i.e.,

$$D = \log \frac{1}{T} = -\log T,$$

where transmittance is the ratio of transmitted energy intensity (I_{out}), to incident energy intensity (I_{in}), i.e.,

$$T = \frac{I_{out}}{I_{in}}$$

Density values are influenced by the measurement conditions, notably aperture sampling size, wavelength of the illumination and angular arrangement of the incident and transmitted energy rays. Relatively large (integrating) apertures produce a "macrodensity" measurement. Smaller apertures (usually less than 500 microns) produce measurements of "microdensity" which are in fact highly dependent upon aperture size and instrumental optics.

DIFFRACTION - Generically refers to the bending of light rays upon interaction with a physical object. The effect cannot be explained with geometrical concepts (as in aberration phenomena), however light wave theory does provide a conceptual basis for explanation of the diffraction phenomenon. Specifically, light waves emanating from an object point passing through an aperture are not totally directed toward the ideal geometrical extension of their original path. Rather, some small portion of energy is diffracted (redirected) into adjacent regions. With respect to a lens system, in which an object point is imaged at a position of best focus, diffraction causes the image to be degraded from a true point to a psuedo point which characteristically consists of a circular center surrounded by concentric rings and is referred to as a point spread function.

DIFFRACTION LIMIT - Refers to a state of optical system correction such that optical performance is limited only by the diffraction of light. A perfect optical system would be ultimately limited by light diffraction which is present in all lens systems with finite aperture.

EXPOSURE - A general term for the amount of light incident on a film. In the simplest photometric terms, exposure (E) is the product of light intensity (I) and time (t), i.e.,

$$E = It,$$

and is usually expressed in meter-candle-seconds. Although exposure for a given scene actually varies from point-to-point in direct relation to scene brightness patterns, the term conventionally refers to the average or nominal value for the scene or series of scenes as a whole. Exposure also can refer to the camera system parameters which define the average intensity and time, e.g., aperture, slit width, shutter speed, film transport speed, image motion compensating speed, and the like. Thus, if exposure is inadequate, either the light level must be increased or the duration of light action on the film must be increased.

ILLUMINATION - A term for the light energy incident on an object. For aerial photography, illumination consists of a combination of direct sunlight and indirect skylight (sunlight scattered by the atmosphere). Its measurement in photometric terms is the luminous intensity per unit area (meter-candles) on some intercepting surface.

INTENSITY - In general, intensity expresses the relative strength of light energy at any given location and instant of time. It is a critical factor in defining photographic exposure, illumination, and luminance. Photometrically, intensity is essentially the rate of flow of luminous flux, i.e., the flux emitted into a solid angle of one steradian by a point source.

LUMINANCE - Generally refers to the amount of light energy emanating from an object. As such, luminance is a measure of brightness. Photometrically, it is the luminous intensity per unit area projected on a plane perpendicular to the direction of measurement given in foot-lamberts.

MODULATION TRANSFER FUNCTION (MTF) - In concept, if sinusoidal brightness variations of known spatial frequencies are photographed, and their modulation in the resulting image is measured, the ratio of output modulation to input modulation over the given frequencies is the MTF. It is used in system design and image quality evaluation.

PHOTOMETRY - The study of light measurement, especially as it related to visual and photographic applications. Photometry normally deals with luminous radiation, that is, radiation which the human eye can detect. Because of some similarity in spectral response and because of the intimate interaction between photographic and visual systems, photometric measurements have been often applied to all forms of actinic radiation in photographic situations.

PRECISION - Refers to the repeatability of measurements (readings) with respect to each other, and not necessarily to a "true" value as in the definition of accuracy. Precision is often expressed as a "range" or "spread" of measurements (readings).

REFLECTANCE - A general expression for that property of an object which determines the amount of incident light redirected away from the object. In the most straightforward sense, the reflectance of an object determines its relative brightness", i.e., luminance is the product of illumination and reflectance. It is this property of reflectance, then, that fundamentally delineates ground information via brightness and consequent film density patterns. The reflectance of an object is spectrally dependent, and this does influence the final density rendition of that object in relation to the rest of the scene. Effective reflectance of an object is also dependent upon the camera-object-sun angle relationships insofar as reflectance is rarely uniform over all possible collection angles. In the extreme, if the camera-object-sun relationship is critical, some information will be masked by the localized flare of specular reflections.

SENSITOMETRIC RESPONSE CURVE - The means for displaying the relationship between developed density in a photographic film and the exposure that the film received. This response of density to exposure is plotted as a linear/log format, i. e. , D (log E), but is really a log/log relationship since density is itself logarithmic. The sensitometric properties of a film result not only from inherent characteristics of the film itself, but also from the exposing, storing, processing, printing, and viewing conditions to which the film is subjected. Without specification of all of these influential parameters, the sensitometric response curve cannot be fully exploited. A typical curve (Figure D-8) has three transitory portions - toe, linear, and shoulder.

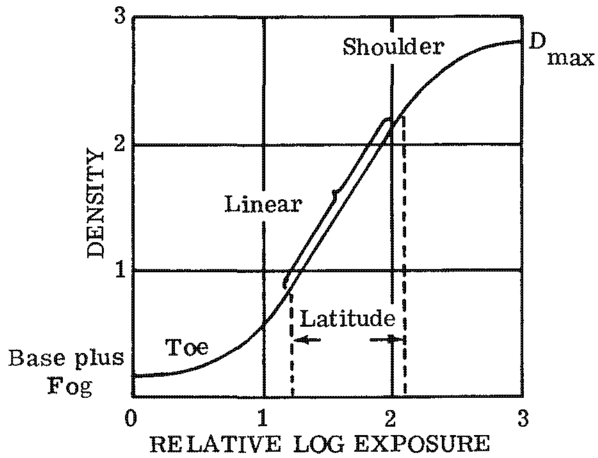

FIGURE D-8

In the toe portion, increasing exposure produces an increasing rate of density change. In this region, information is lost due to a compression of distinguishable density levels. This is the region of underexposed photography; where shadow detail is often lost even in well exposed scenes. A minimum density boundary is set by the inherent transmission of the supporting substrate material coupled with some residual silver development even in the total absence of exposure; this is referred to as the "base plus fog" level. In the shoulder portion, increasing exposure produces a decreasing rate of density change, also resulting in information degradation due to the distinguishable density level compression. This is the region of overexposed photography; and even with well exposed scenes, highlight detail is often lost in this region. The maximum density attainable under the specific processing conditions is signified by "D_{max}". In the straight line portion of the curve the density response to log exposure is essentially linear. The extent of the linear portion along the log E axis defines an exposure "latitude", the sensitometric property which reveals just how accurately good exposure must be pinpointed in some particular set of circumstances.

THRESHOLD MODULATION CURVE - The relationship for a photographic film which defines the minimum modulation required to achieve any resolution level over some dynamic range. The curve is generated experimentally by photographing tribar targets onto the test film at a series of input contrasts and statistically determining the resultant resolving power levels. In general, higher contrast yields higher resolution. The resultant curve characterizes the threshold boundary of minimum modulation needed to achieve equivalent tribar spatial frequency rendition over the range of values tested. As with the sensitometric response curve, parameters associated with exposure and processing conditions must be specified if the curve is to be specifically applicable to some actual situation. These curves have been referred to by other names, e. g. , aerial image modulation (AIM) curves, emulsion threshold curves, emulsion detectability curves and the like; but threshold modulation (TM) curve is the IRARS nomenclature.