

THE PHYSICAL PROPERTIES AND DIMENSIONAL STABILITY OF SAFETY AEROGRAPHIC FILM*

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I. INTRODUCTION

SAFETY base aerial film has now been in use in the United States for topographic mapping work for nearly ten years. When it first began to replace nitrate film because of its freedom from hazard and its long-time chemical stability, there was doubt in some quarters regarding the ability of the safety film to perform satisfactorily. Many of the early types of cellulose acetate film suffered from high shrinkage and from excessive brittleness when dry. However, an improved type of safety film for aerial mapping was developed by the Eastman Kodak Company about 1937 which, it was felt, was the equal of nitrate in dimensional stability under normal conditions and only slightly inferior in other physical characteristics.

Since its introduction, safety topographic aerial film has gained wider and wider acceptance, and for the past few years has been used almost exclusively in this country. The saving which has resulted from the reduced fire protection requirements for the handling and storage of the film, together with the advantages gained in permanence for such valuable records, has been incalculable. These facts alone more than justify the early hopes that were felt for safety aerial film. Nevertheless, errors have been encountered from time to time in the preparation of accurate topographic maps which, rightly or wrongly, have been attributed to distortion or shrinkage in the aerial negative, and the thought is still occasionally expressed that the old nitrate base was superior to the safety in dimensional stability. We are firmly convinced that this is not generally the case, although there may be individual exceptions.

The shrinkage characteristics of the first Kodak Safety Aeronographic Film¹ were described before this Society by E. K. Carver in September 1938, and it was shown that the dimensional stability of the safety was practically equal to that of the nitrate (1).² Since that time numerous changes have been made, and more experience has been gained in both the manufacture and use of this type of film. At the same time map making instruments and techniques have been continually improved and greater accuracy is desired. Therefore, it was felt that this might be an appropriate time to review the dimensional behavior of various Kodak Aeronographic Films manufactured during the past ten years and to describe some of their fundamental physical characteristics. It is hoped that this information will prove of practical value to photogrammetrists and at the same time stimulate further investigations with the object of reducing dimensional variations in aerial negatives under operating conditions.

A study of the dimensional behavior of nitrate aerial films and photographic

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¹ Note: To avoid confusion it is necessary to clarify recent Kodak film name changes. The topographic base film (Army Type IA) was originally named "Eastman Safety Topographic Aero Film." In 1945 this was changed to "Kodak Safety Aeromap Film" and the non-topographic, or reconnaissance base film (Army Type IB) was called "Kodak Safety Aeronographic Film." With the end of the war, the Type IB reconnaissance base film was discontinued entirely and the name "Kodak Safety Aeronographic Film" applied to the Type IA topographic base film. In the present article the name "Kodak Safety Aeronographic Film" has been used throughout and in all cases refers only to the topographic, or low-shrink type of base.

² Numbers in parenthesis refer to papers listed in "References," pp. 219-220.

papers was made at the Bureau of Standards about 1937 (2). The films investigated then are now obsolete, but much of the information obtained is still valuable to those concerned with film shrinkage. A small amount of data on the shrinkage of modern safety topographic aerial film is given in a review of photographic materials for aerial photography in 1944 (3). About the same time a detailed description of the dimensional behavior and physical properties of motion picture film was given, much of which is applicable in principle to aerial film as well (4). More recently, P. D. Carman has described dimensional changes occurring in safety topographic aerial film under actual service conditions (5).

II. MANUFACTURE OF AEROGRAPHIC BASE

The essential physical requirements of a topographic aerial film base are:

- (1) It must have sufficient strength and flexibility to withstand all normal handling.
- (2) The total shrinkage or expansion between exposure and printing must be as low as possible.
- (3) Any dimensional changes which do occur must be as nearly equal as possible in the length and width directions.

It is generally considered that the last of the above requirements is the most important from the point of view of dimensional stability, because most aerial negatives intended for mapping purposes are printed by projection. Any dimensional change which is the same in all directions can be readily corrected, whereas any image distortion caused by a greater shrinkage or expansion in one direction than another cannot be corrected. However, the total dimensional change must also be held low, because no matter how small the difference between length and width, this difference becomes greater as the magnitude of the overall shrinkage or expansion increases.

The Choice of Cellulose Ester

Before discussing the physical properties of Safety Aerographic Film, it is necessary to clarify a commonly-held fallacy regarding the chemical composition of the base. For many years, the only safety base for photographic film was made from a regular acetone-soluble cellulose acetate and gradually the terms "safety" and "acetate" came to be used interchangeably. Actually, there are many cellulose esters³ and their properties vary radically with the type and number of acid groups introduced into the cellulose molecule. In addition to various cellulose acetates, there are cellulose propionates and cellulose butyrates as well as mixed cellulose esters, all of which are often loosely referred to as "acetate." As a matter of fact, ordinary acetone-soluble cellulose acetate has never been used in Kodak Safety Aerographic Film base, but only the mixed cellulose esters such as cellulose acetate propionate and cellulose acetate butyrate or (recently for a brief period) a high acetyl cellulose acetate. This is an important distinction because the dimensional stability and other physical properties of the film depend as much on the type of cellulose ester employed in the base as upon the manufacturing process.

The composition diagram for cellulose esters of acetic and butyric acids, taken from the data of Malm, Fordyce and Tanner (7) is shown in Figure 1. The corresponding diagram for cellulose esters of acetic and propionic acids is similar. The area between the diester and triester lines in Figure 1 represents the

³ An ester is a chemical compound resulting from the reaction of an acid with an alcohol. In this case, the alcohol or hydroxyl groups are in the cellulose molecule and the acid may be nitric acid, acetic acid, propionic acid, butyric acid, etc. Those interested in the chemistry of cellulose derivatives are referred elsewhere for more detailed information (6, 7).

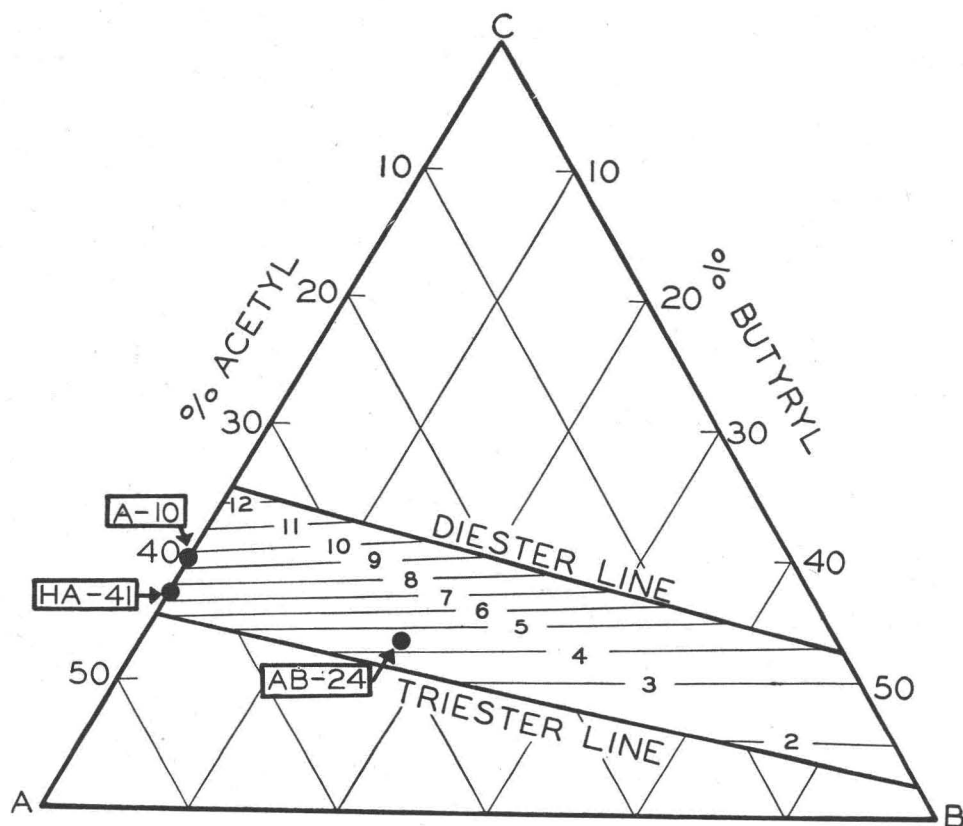


FIG. 1. Composition diagram showing percent sorption of moisture by cellulose esters of acetic and butyric acids at 90% R.H., 77°F.

practical limits for commercial film forming materials. The composition of any ester can be represented by a point along the edges or within the triangle down to the triester line, which corresponds to complete esterification. For example, the cellulose acetate butyrate used in the present Kodak Safety Aerographic Film base contains approximately 29.5% acetyl and 17.5% butyryl, and is represented by the point AB-24 in the diagram. The point A-10 represents a regular acetone-soluble cellulose acetate (never used in Aerographic film base), and HA-41 is the high acetyl acetate which has been used in Aerographic film base.

A low moisture absorption is one of the most important requirements of a cellulose ester which is to be used for a dimensionally stable film base, because the film expands and contracts with gain and loss of moisture. In this respect, ordinary cellulose acetate suffers considerably in comparison with cellulose nitrate. The equilibrium moisture content of the cellulose esters of acetic and butyric acids at 90% relative humidity (shown by the horizontal lines in Figure 1) varies from less than 2% to over 12% depending on the ratio of acetyl to butyryl and on the degree of esterification. It may be seen that the acetate butyrate, AB-24, absorbs only 4-5% moisture at 90% R.H. compared with 9-10% moisture for the regular acetate, A 10. The moisture content of cellulose nitrate of the type used in film base is approximately 4% under the same conditions. Unfortunately, the cellulose acetate butyrates having the lowest moisture

absorption do not make good films because other properties such as solubility, tensile strength, brittleness, and so forth, become less desirable as the moisture resistance improves. For this reason it is necessary to make a number of compromises, and relatively few cellulose esters have been found satisfactory for topographic aerial film base.

The chemical composition and moisture absorption of all the cellulose esters, both safety and nitrate, which have been used for Aero-graphic film base at different times is given in Table I. (A low nitrogen cellulose nitrate, and a regular

TABLE I. THE COMPOSITION AND EQUILIBRIUM MOISTURE CONTENT OF VARIOUS SAFETY AND NITRATE EASTMAN CELLULOSE ESTERS AND CORRESPONDING KODAK AEROGRAPHIC FILM SUPPORTS

Type	Nitrate	Nitrate	Nitrate	Regular Acetate	Acetate Propionate	Acetate Butyrate	High Acetyl Acetate	
Cellulose Ester								
Designation of Ester	N-01*	N-02	N-04	A-10*	AP-31	AB-24	HA-41	
Composition								
Nitrogen, %	11.10	12.20	11.95	—	—	—	—	
Acetyl, %	—	—	—	40.4	30.0	29.5	43.3	
Propionyl, %	—	—	—	—	16.0	—	—	
Butyryl, %	—	—	—	—	—	17.5	—	
Moisture Absorption at 90% R.H., 77°F., %	6.0	3.8	4.3	9.8	4.2	4.5	7.5	
Aero-graphic Film Base								
Designation of Base		N-025	N-045	A-107*	AP-311	AB-244	AB-284	HA-417
Date of Manufacture		1936-39	1940-43	—	1937-40	1941-42	1943-47	1946
Moisture Absorption at 90% R.H., 70°F., %		2.0	2.2	5.5	1.9	2.4	2.5	3.5

* These esters and film support were never used for Kodak Aero-graphic Film. The data are included only for comparison.

acetone-soluble cellulose acetate, neither of which were ever used for Aero-graphic film base, are included in this table merely for comparison purposes.) The location of several of the safety cellulose esters in the composition diagram, Figure 1, has already been mentioned. The data in Table I show that the moisture absorption of cellulose nitrate varies with the degree of nitration (percent nitrogen) just as the moisture absorption of the slow-burning cellulose esters varies with the percent acetyl, propionyl, or butyryl present. It will be observed that the moisture absorption of the mixed cellulose esters (AP-31 and AB-24) is very nearly the same as that of cellulose nitrate of the type used in film base. The moisture absorption of the high acetyl acetate (HA-41) is somewhat higher, but still considerably less than that of an ordinary cellulose acetate, such as A-10. Furthermore, it has been possible to reduce the moisture absorption of the cellulose esters still more by the incorporation of suitable plasticizers in the film base as demonstrated by the data in the lower half of Table I. It will be observed that the Safety Aero-graphic Film supports compare very favorably with the Nitrate Aero-graphic base in moisture absorption. This cannot be accomplished with a regular cellulose acetate.

The high acetyl acetate type of Aerographic film base (HA-411, Table I) was made for only a few months during 1946. It was not continued partly for manufacturing reason and partly because it did not prove to be quite as dimensionally stable as the previous acetate butyrate base (AB-284). The latter, therefore, remains the standard Safety Aerographic Film base today. The properties of each of these films will be described in subsequent sections.

Casting the Film Base

The actual casting of film base from a solution or dope of the cellulose ester, together with plasticizer, in suitable organic solvents has already been described a number of times (1, 4, 6). The operation consists essentially of spreading a thin layer of dope on a slowly revolving, highly polished roll and evaporating the solvent at such a rate that a self-supporting skin can be stripped from the metal surface before one revolution is completed. The film base is then cured by passing it through a series of heated chambers to remove the residual solvent.

Some knowledge of the structure of cellulose ester films is required at this point. Cellulose and cellulose ester molecules are believed to consist of long chains and these may or may not be grouped together in bundles sometimes called *miscelles*. Evidence obtained from studies of the mechanical and optical properties of these films indicates that whatever the nature of the particles, they must be unsymmetrical in shape with one axis considerably longer than the others (6, 8). This is important because it means that solvents or moisture absorbed by the cellulose ester will have a relatively greater swelling effect in the short dimensions of the molecule. (The attachment of solvent or water molecules to a rod shaped cellulose ester molecule, will make a large percentage increase in diameter but not a large percentage increase in length.) An isotropic film—that is, a film having a completely random structure—will swell in water equally in all three dimensions even though the constituent particles are unsymmetrical. On the other hand, any orientation of the molecules in one direction or another will result in unequal swelling in the three dimensions of the sheet. In the case of topographic aerial film, it is only necessary that the base be uniaxial—that is, there should be no molecular orientation in the length or width of the sheet—so that any expansion or contraction caused by changes in humidity or temperature will be the same in both principal directions. (A greater percentage swell in the thickness of the sheet would be of no importance.)

In the manufacture of topographic aerial film base, it is the curing operation which is most critical because of the danger of stretching. If the base is stretched while it still contains appreciable amounts of solvent, or while it is still softened by heat, some of the cellulose ester *miscelles* or molecules become oriented in the lengthwise or coating direction. If the base is stretched after it becomes partially hardened, but while it is still warm, a mechanical strain may be "frozen-in." If this strain is relieved during the life of the film, it will cause a lengthwise shrinkage and a widthwise expansion (9). Both of these effects may cause image distortion in aerial negatives and both must be reduced to the absolute minimum in the manufacturing operation. The residual solvent content of the base must also be reduced to as low a level as possible to minimize permanent shrinkage. However, any increase in curing temperature made to lower the residual solvent, also increases the ease of stretching the film base. It is therefore only by the most careful control of the curing operation that the rigid requirements of a topographic aerial film base can be met.

III. MOISTURE RELATIONS

The importance of a low moisture absorption for a topographic aerial film has already been mentioned in connection with minimizing humidity dimensional changes. Other important physical properties such as strength, flexibility, brittleness, curl, and so forth, are all dependent on the moisture content of the film. The effect of liquid water is likewise important in connection with processing. For these reasons, the influence of moisture on topographic aerial film should be clearly understood. The information given elsewhere (4) on the rate of absorption of water, the rate of drying, and so forth, for motion picture film applies in a large measure to aerial film as well and need not be repeated here.

The Sorption of Moisture by Aerographic Film

To many people it comes as a surprise that film or paper should hold different amounts of moisture at different relative humidities. This is probably

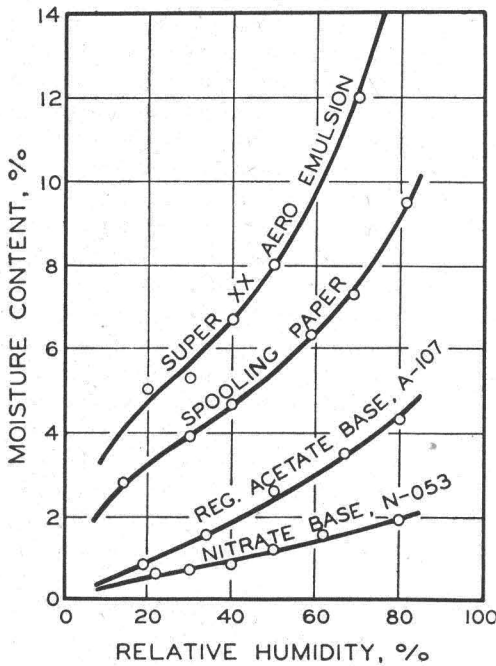


FIG. 2. The equilibrium moisture content of photographic emulsion, paper and film base at various relative humidities at 70°F.

because different degrees of dryness cannot easily be detected by sight or touch. The manner in which the equilibrium moisture content of a number of common photographic materials varies with the relative humidity of the surrounding air is shown in Figure 2. Photographic emulsion, which is mainly gelatin, absorbs a relatively large amount of moisture. Paper, a form of native cellulose, absorbs a little less and cellulose acetate and cellulose nitrate film base absorb still less moisture at any given relative humidity. The difference in the moisture absorption of these materials is caused by differences in both chemical composition and physical structure. The increasing steepness of the curves in Figure 2 at high relative humidities is noteworthy, because it explains why the effects of moisture on the physical properties of film become increasingly pronounced at these conditions.

Moisture absorption curves for several types of Safety Aerographic Film base compared with nitrate and regular acetate are given in Figure 3. (Comparable data on Nitrate Aerographic Film base, type N-045, which has not been manufactured for several years, is unavailable. However, N-053 is chemically very similar and provides a reliable comparison for the purpose.) It will be observed that the first Kodak Safety Aerographic Film base (AP-311) which was rather highly plasticized, actually has a lower moisture absorption curve than the nitrate. The present acetate butyrate Aerographic base (AB-384) is only slightly higher than the nitrate and much lower than the regular acetate (A-107). The curve for the high acetyl acetate (HA-411) falls between these two.

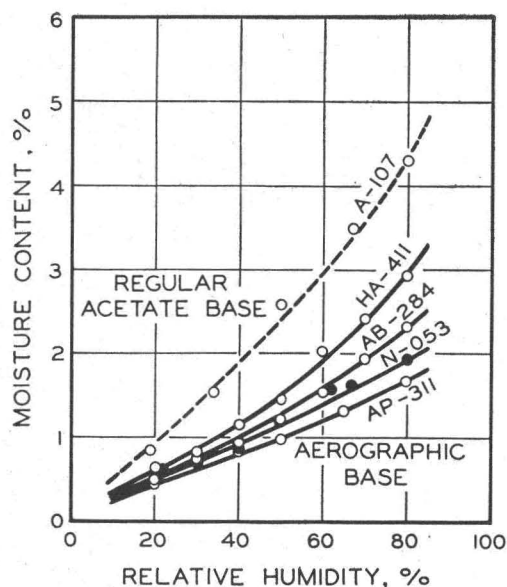


FIG. 3. The equilibrium moisture content of Kodak Safety Aerographic Film base (AP-311, AB-284, HA-411), compared with nitrate (N-053) and regular acetate base (A-107) at various relative humidities at 70°F.

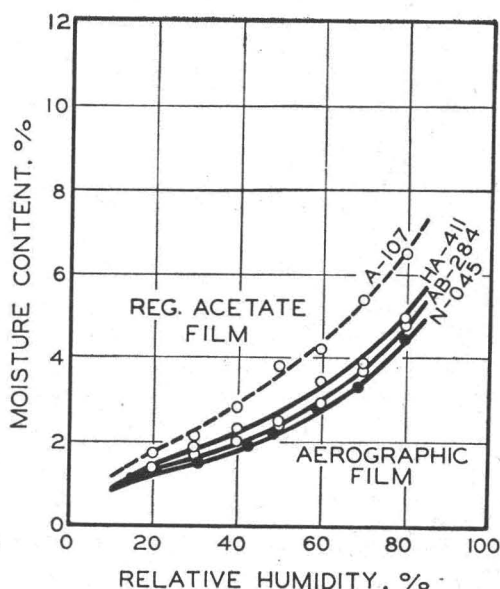


FIG. 4. The equilibrium moisture content of Kodak Safety (AB-284, HA-411) and Nitrate (N-045) Aerographic Film compared with regular acetate (A-107) at various relative humidities at 70°F.

Similar moisture absorption curves are given in Figure 4 for several emulsion coated Aerographic films compared with regular acetate film. The moisture content of the finished film at any relative humidity is higher than for the corresponding base because of the moisture absorbed by the emulsion layer. However, the relative positions of the curves remain unchanged, demonstrating again how much more closely the present acetate butyrate Aerographic film (AB-284) approaches the nitrate in moisture resistance compared with regular acetate film.

It should be emphasized that the *relative* humidity, not the *absolute* humidity, is the controlling factor in determining the moisture content of photographic film, as well as paper and other moisture absorbing materials. This means that the equilibrium moisture content of the film at any given relative humidity is nearly the same regardless of temperature. Actually, paper, cellulose derivatives and similar materials absorb slightly more moisture when the temperature is lowered and the relative humidity held constant (6, 10). Recent work on various textile yarns by Darling and Belding (11) suggests that there is a maximum in the moisture content versus temperature curve (at constant relative humidity) near the freezing point, above and below which the moisture content decreases. This is questioned by Whitwell and Toner (12), and undoubtedly the moisture relationships of these materials at below freezing temperatures is still uncertain. In any event, the effect of temperature at constant relative humidity on the moisture content of film is very small compared with the effect of relative humidity at constant temperature.

Hysteresis

The phenomenon of hysteresis should be mentioned here. If gelatin, cellulose or its derivatives, or similar materials are first dried out and then allowed to

condition at 50% R.H., for example, they will be found to contain a slightly smaller amount of moisture than if first brought to a high moisture content and then conditioned at the same relative humidity (6, 10). Since humidity dimensional changes in film closely parallel the moisture content, small errors can be introduced if a film is conditioned at a given relative humidity first from one side and then from the other side. This point is referred to again in later sections.

The Rate of Conditioning of Film

In many operations with aerial film, it is of interest to know the rate at which moisture is given up or absorbed when the ambient relative humidity is changed, because the rate of conditioning of film is closely related to the rate at which film attains dimensional equilibrium. Rate of conditioning curves can be

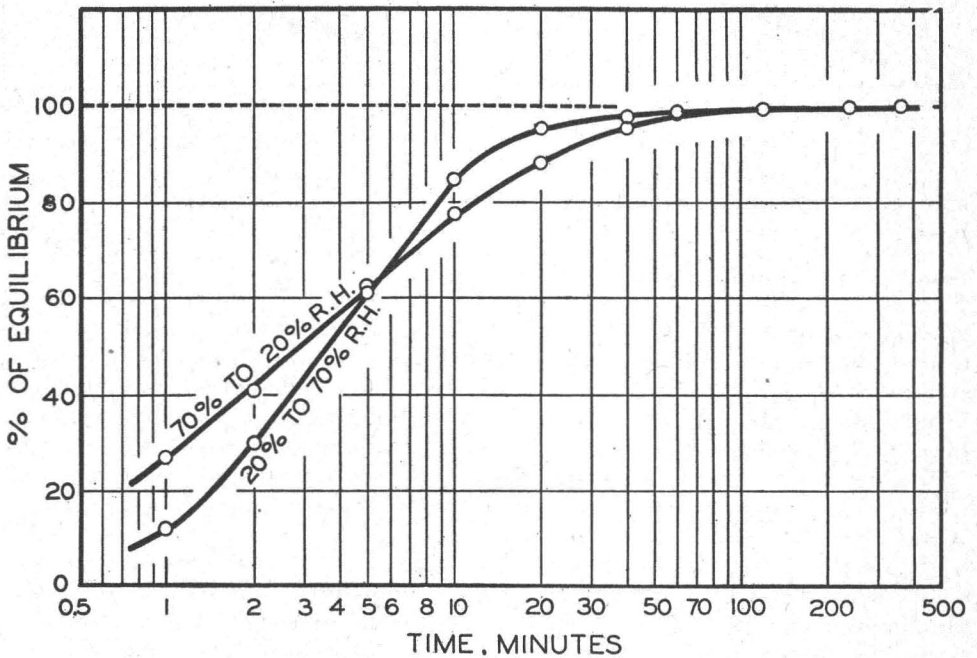


FIG. 5. The rate of conditioning of Kodak Safety Aerographic Film (Type AB-284 base) from one relative humidity to another at 70°F. Air velocity probably under 1 ft. per second.

determined by measuring the change in weight of film samples with time after suddenly altering the relative humidity of the surrounding air. Rate of conditioning curves for Safety Aerographic Film obtained in this way are plotted in Figure 5, the change in weight being expressed as a per cent of the total change at equilibrium.

It will be observed from the slope of the straight line portion of the curves in Figure 5, that after the first minute the rate of adsorption of moisture from 20% to 70% R.H. is appreciably greater than the rate of desorption from 70% to 20% R.H. This is believed to be due to the rapid initial drying of the outer emulsion layer in the desorption process which retards the diffusion of moisture from the interior of the film to the surface. In both cases the time required to reach 90% of equilibrium under the conditions of the experiment is approximately 15 to 20 minutes, whereas complete equilibrium requires several hours.

The rate of conditioning of film is, of course, affected by the temperature, the air velocity, the initial and final relative humidity and so forth.

The Effect of Temperature on the Rate of Conditioning Film

The effect of temperature on the rate of conditioning aerial film is of special interest because of the low temperatures common in aerial cameras at high altitudes. If the air in the camera is at a different relative humidity from that with which the film is in equilibrium, an exchange of moisture will occur which may alter the dimensions of the film just prior to exposure. Darling and Belding (11) recently reported that the rate of adsorption of moisture by cellulose acetate and other textile yarns more than doubled for every 10°C. increase in temperature between -20°F. and 40°F. This means that at subzero temperatures the rate of conditioning is extremely low.

An experiment was undertaken to determine the rate of conditioning of Safety Aerographic Film from a low to a high relative humidity at subzero temperatures. Samples of film were conditioned at 20% R.H. at 70°F., placed in glass stoppered bottles and weighed. These were cooled to -10°F. in a constant temperature cold room before opening, and the samples then placed in a metal chamber in the same room. Air passing over constant temperature ice-coated brine coils was drawn through the chamber at a linear velocity of about 1 ft. per second. Separate film samples were removed and weighed at appropriate time intervals.

The accurate determination of the relative humidity of air at below freezing temperatures is extremely difficult because of the low absolute humidity, and because the difference between the wet bulb (or ice bulb) temperature and the dry bulb temperature is so small. Furthermore, there is some ambiguity over the definition of relative humidity below 32°F. because the partial pressure of water vapor in the air corresponds to the vapor pressure of sub-cooled water considerably below the freezing point (13, 14). Since the vapor pressure of subcooled water is significantly higher than the vapor pressure of ice, relative humidity at below freezing temperatures is more often defined as the ratio of the partial pressure of water vapor in the air to the vapor pressure of subcooled water at the same temperature, multiplied by 100. This avoids the anomaly of relative humidities above 100%.

A hair hygrometer calibrated at room temperature indicated the relative humidity in the -10°F. chamber to be between 80% and 90%, which is believed to be high because the air temperature was several degrees above the ice temperature. A further check was made by conditioning Aerographic film samples at known relative humidities at above freezing temperatures and determining the direction of the weight change in the -10°F. chamber. Film conditioned at 69% R.H. was found to gain 0.38% in weight, whereas film conditioned at 78% R.H. was found to lose 0.40% weight. This would indicate the relative humidity in the -10°F. experiment to be in the neighborhood of 75%, although this may not be correct if the relationship between equilibrium moisture content and relative humidity for the film is appreciably different at -10°F. than at 70°F. In any event, our primary concern here is with rates of adsorption and the exact relative humidity is not needed for this purpose.

In Figure 6 the moisture adsorption of the film at any time is calculated as a percent of the equilibrium value for both -10°F. and 70°F. It may be seen that whereas the film reaches 90% of equilibrium in about 15 minutes at 70°F., as many hours are required at -10°F. Complete equilibrium, which requires several hours at 70°F., takes at least a week at -10°F. From the data in Figure 6 the temperature coefficient for the moisture adsorption of the film has been

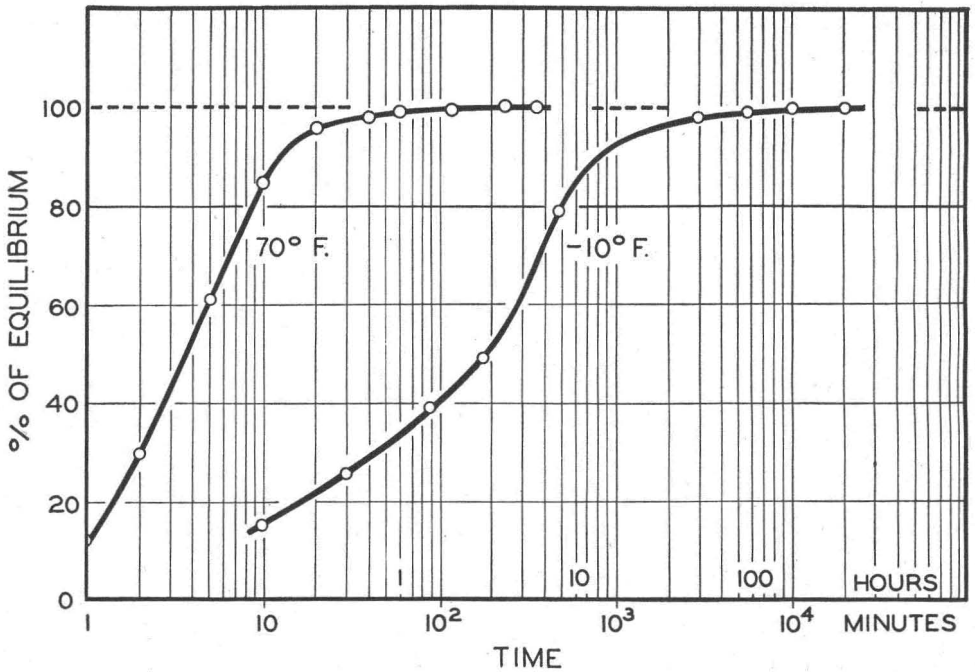


FIG. 6. The effect of temperature on the rate of adsorption of moisture by Kodak Safety Aerographic Film (Type AB-284 base). Initial relative humidity approximately 20%, final 70-75%; linear air velocity about 1 ft. per second.

calculated to be 2.5 to 2.7 per 10°C . in the temperature range studied, which agrees well with the values of 2.1 to 2.6 reported by Darling and Belding for wool yarn (11). From the temperature coefficient, the rate of adsorption at any other temperature can be readily estimated. However, the rate of desorption of moisture from film at low temperatures may be somewhat different from the rate of adsorption because of various complicating factors.

IV. MECHANICAL PROPERTIES

Some of the mechanical properties of the various Aerographic films will be described before discussing their dimensional stability. A satisfactory topographic aerial film has very exacting physical requirements. It must have sufficient flexibility, it should be free from objectionable brittleness and curl, and it should not break, tear or stretch in any of the operations involving exposure, processing or printing. Unfortunately, it is seldom possible in selecting a film base to obtain all of the characteristics desired and it is usually necessary to compromise between one property and another to make an all around satisfactory film. Topographic aerial film should be capable of meeting these physical requirements under any climatic condition likely to be encountered in practice. However, like most organic plastics, photographic film is rather sensitive to extremes of either temperature or relative humidity. A knowledge of the effect of these variables on the mechanical properties of film will frequently help in obtaining reasonably satisfactory performance under adverse conditions.

The mechanical behavior of plastics like film base is entirely different from that of other materials, such as metals. Furthermore, the mechanical properties of plastics are particularly dependent on the mode of manufacture, and films made from the same composition may differ radically in their behavior. When

a plastic is subjected to a stress (in tension, compression, flexure, or torsion), the resulting deformation increases with time and the material does not return to its original dimensions on removal of the stress. This dependency of the mechanical behavior of plastics on the time factor has many important practical applications in the performance of photographic film which will become apparent as we proceed. Those interested in the theoretical background for this discussion are referred elsewhere for more detailed information (6, 15, 16, 17).

In the development of improved types of film base as well as in manufacturing control, it is impractical to evaluate every film by actually running it through a camera, processing machine, and printer, under a variety of atmospheric conditions. For this reason a number of empirical mechanical tests are performed in the laboratory which, experience has shown, give results correlating fairly well with practical film performance. Some of the testing instruments employed for determining tensile strength, folding endurance, tearing resistance, and so forth, are in common use in the paper industry, and others have been specially built for testing film. The results of such tests are useful in comparing different films although, of course, final approval depends on satisfactory practical performance.

Tensile Strength

More information concerning the mechanical behavior of plastics can probably be obtained from a determination of their stress-strain relationships than by any other single test. Exact values for the tensile properties of plastics vary with the type of testing machine employed and the speed at which it operates, because some plastic flow occurs even below the elastic limit. However, except for theoretical studies, it is the relative difference between materials tested under the same conditions which is usually most important. Stress-strain curves for film base have been made by means of a Schopper dynamometer operating at a speed of 100 mm. per minute. The type of curve obtained with cellulose acetate butyrate Aero-graphic film base is illustrated in Figure 7. An analysis of the stress-strain curve indicates whether a material is soft, hard, weak, strong, brittle, tough, etc. The slope of the first portion of the curve, where stress and strain are roughly proportional, is a measure of stiffness. The stress at the first inflexion point, called the yield point, indicates the resistance of the material to plastic deformation, and the maximum stress reached before rupture is the tensile strength. All of these characteristics are important in topographic aerial film.

The tensile strength and ultimate elongation of each type of Safety and Nitrate Aero-graphic Film base are recorded in Table II. (The composition of the respective cellulose esters may be found by reference to Table 1.) The

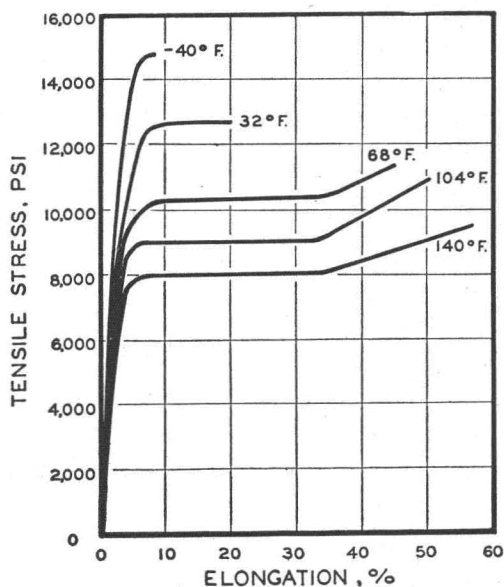


FIG. 7. Stress-strain curves for Kodak Safety Aero-graphic Film base (Type AB-284) at different temperatures. (Samples dried over calcium chloride.) Schopper dynamometer at 100 mm. per minute.

TABLE II. THE APPROXIMATE MECHANICAL PROPERTIES OF KODAK SAFETY AND NITRATE AERCGRAPHIC FILM BASE
(All measurements made at 70°F., 50% R.H.)

Property	Designation	N-025	N-045	AP-311	AB-244	AB-284	HA-411
	Type of Base	Nitrate	Nitrate	Acetate Pro-pionate	Acetate But-yrate	Acetate But-yrate	High Acetyl Acetate
	Date of Manufacture	1936-39	1940-43	1937-40	1941-42	1943-47	1946
Direction of Test							
Tensile Strength (Schopper), psi.	Length Width	16,800 15,800	16,000 15,100	8,600 8,000	11,800 10,800	10,800 10,200	15,500 14,600
Ultimate Elongation, %	Length Width	34 39	33 35	37 41	37 42	44 49	32 35
Modulus of Elasticity in Tension, 10 ⁵ psi.	Length Width		6.7 —	3.5 —	4.8 4.4	4.6 4.5	5.8 5.5
Plastic Flow,* %	(1) Length		0.15	—	—	0.40	0.21
	(2) Length Width		0.26 0.32	0.78 0.81	0.49 0.54	0.46 0.51	0.33 0.35
Folding Endurance (Schopper), No.	Length Width	25 23	21 22	11 9	17 16	11 11	14 14
Tearing Resistance (Elmendorf), Grams	Length Width	105 103	63 64	49 51	49 54	47 49	48 49

* (1) 5,000 psi. tension for 2 hours at 70°F., 50% R.H.; 2 hours recovery at 70°F., 50% R.H.
(2) 2,000 psi. tension for 1 week at 120°F.; 2-3 hours recovery at 70°F., 50% R.H.

first Safety Aerographic base (AP-311) did represent a considerable loss of strength compared with nitrate, but the present base (AB-284) is somewhat better in this respect. The best Safety Aerographic base from the point of view of tensile properties is the high acetyl acetate (HA-411), although this film has other disadvantages as yet. (See Section V.) The difference between the lengthwise and widthwise tensile properties of the base (Table II) is caused by slight molecular orientation in the machine direction. This reduces the tensile strength and increases the ultimate elongation in the cross direction. However, the difference between the length and width tensile properties of Aerographic base is extremely small compared with motion picture film base (4) or Non-Topographic Aero base.

The effect of atmospheric conditions on the tensile properties of topographic aerial film is particularly important in practice. The influence of temperature on the stress-strain curve is shown in Figure 7. The film base gradually changes from a hard, tough material at normal temperatures, becoming a little softer at 160°F. and relatively brittle, and non-ductile at -40°F. This is illustrated more clearly in Figure 8 where several of the tensile properties are plotted against temperature. The tensile strength and yield stress decrease, and the ultimate elongation increases, with increase in temperature. At the lower temperatures the material breaks very shortly after the yield point is reached. From these

curves it is readily apparent that film is more easily stretched at elevated temperatures, which should be avoided for this reason. Temperatures around 140°F., can be safely used in the drying of topographic aerial film, for example, only if the tension employed is virtually zero. The difficulties encountered at subzero temperatures are discussed in the section on brittleness.

The effect of relative humidity on the tensile strength and ultimate elongation of Safety Aerographic Film base is shown by the curves in Figure 9. The strength decreases and the elongation increases with increase in relative humidity. This is apparently due to a softening or plasticizing action of moisture between the molecules of the base. From a practical point of view it means that film becomes weaker and is more easily stretched or distorted at high relative hu-

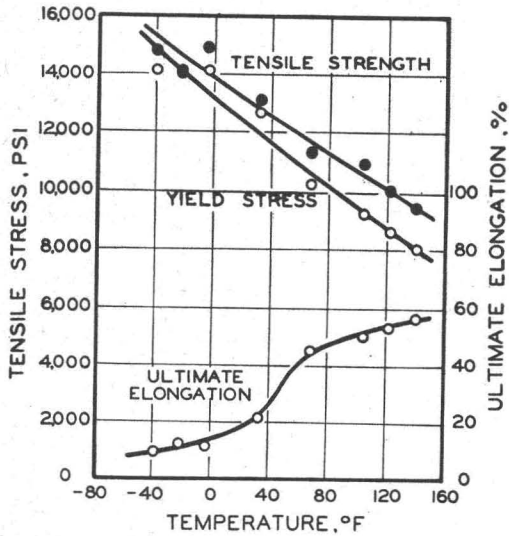


FIG. 8. The effect of temperature on the tensile strength, yield stress and ultimate elongation of Kodak Safety Aerographic Film base (Type AB-284) dried over calcium chloride.

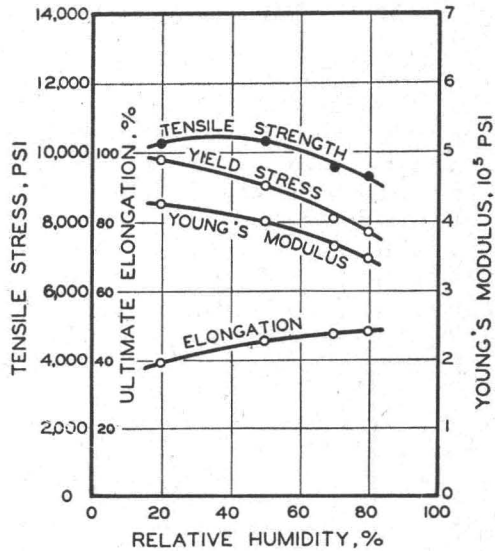


FIG. 9. The effect of relative humidity on the tensile strength, yield stress, Young's Modulus, and ultimate elongation of Kodak Safety Aerographic Film base (Type AB-284) at 70°F.

midities or when actually soaked in water. This should be remembered in the handling of aerial films in processing machines.

Modulus of Elasticity

The modulus of elasticity, or Young's Modulus, is the ratio of stress to strain in the initial straight line portion of the stress-strain curve. It is one of the most important mechanical properties of a topographic aerial film base, because it is a measure of stiffness or resistance of the material to deformation under stress. This not only affects the dimensional stability of the film, but also such properties as curl. Data on modulus of elasticity are useful in calculating the elastic deformation which may be expected when film is subjected to various amounts of tension in cameras, processing machines, etc.

The modulus of elasticity of a material can be determined by measuring the slope of the initial straight line portion of the stress-strain curve, but this is a crude and inaccurate method in the case of films tested by means of a Schopper dynamometer as is apparent from the curves in Figure 7. Our procedure has been to apply a small static load well below the elastic limit (approximately, 1,000 psi.)

to a strip of film and quickly measure the increase in separation between two gage marks inscribed on the sample 10 inches apart. Measurement is made by means of two shop microscopes mounted on a steel bar and is accurate to about 0.01% extension as compared with only 0.5% to 1% by the dynamometer method. This procedure has the added advantage that any slippage in the clamp, introduces no error.

The modulus of elasticity of the various Aerographic films is recorded in Table II. As in the case of tensile strength, the safety films are not yet as good as the nitrate in modulus of elasticity, although marked improvements have been made since the first Safety Aerographic base (AP-311) was introduced in 1937. The effect of atmospheric conditions on the modulus of elasticity of film generally parallels the effect on tensile strength. The modulus decreases with increase in relative humidity (Figure 9) and with increase in temperature.

Plastic Flow

If a plastic such as film base is subjected to a small stress, the deformation produced increases with time and the material does not return to its original dimensions on removal of the stress. A description of this phenomenon has been given previously in connection with motion picture film (4), but will be repeated briefly here because of its importance in topographic aerial film in connection with dimensional stability. The behavior of a plastic material under a constant tension (well below the yield point) is illustrated by the creep curve for nitrate film base, Figure 10. Three distinct phenomena occur—first, an instantaneous elastic deformation which is instantly recovered on removal of the load. This is followed by a flow or creep, which gradually decreases in rate provided the yield

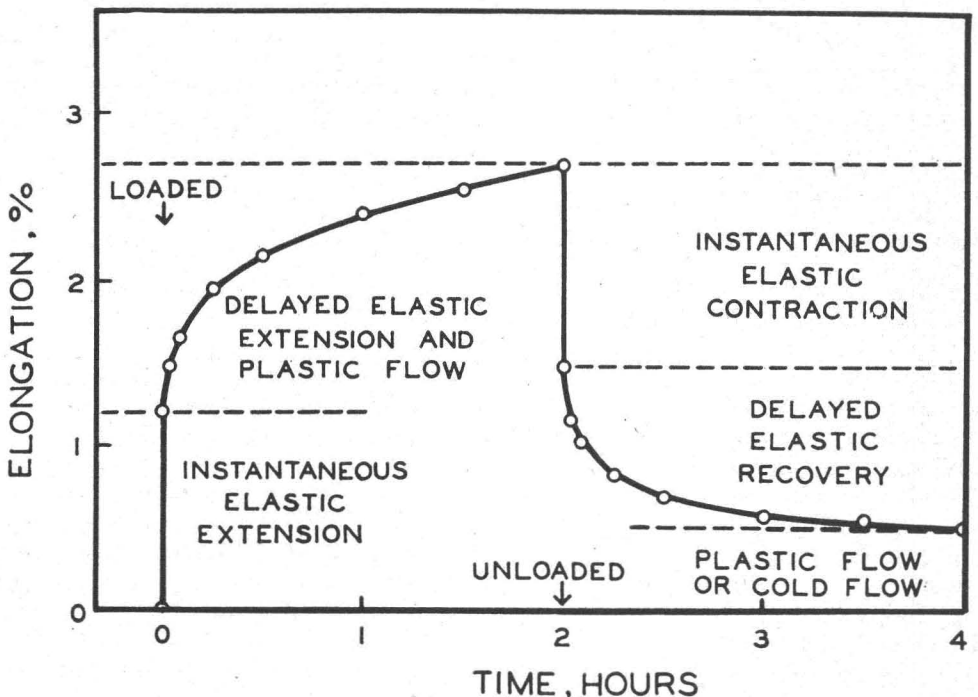


FIG. 10. Typical flow (or creep) and recovery curve for cellulose ester film under constant tension. Cellulose nitrate film base; load 7,400 psi; conditions, 70°F., 50% R.H.

point is not exceeded. Creep is made up of two components, a delayed elastic deformation, sometimes called *primary creep*, which is recovered slowly on removal of the load; and a plastic deformation, called *plastic flow*, *cold flow*, or *secondary creep*, which is not recovered on removal of the load (6, 15, 16).⁴

The magnitude of the plastic flow or cold flow which a film will undergo increases with increase in the stress applied, the time during which it acts and the temperature and moisture content of the material. This is one of the most serious sources of dimensional change in topographic aerial film. The delayed elastic deformation, primary creep, may also be a cause of film shrinkage. The recovery of primary creep is greatly retarded if the temperature or moisture content is decreased while the film is still under load. This has been referred to in an earlier section as the "freezing-in of strain." If the film is then returned to its original temperature or moisture content at some later time after removal of the load, a shrinkage will occur in the direction of the original stretch, and an expansion will occur normal to the direction of stretch.

The plastic flow of different films under the same conditions depends on their chemical composition and mode of manufacture. Table II gives the plastic flow of both Safety and Nitrate Aerographic Film supports under two different conditions, 5000 psi. for 2 hours at 70°F., 50% R.H. and 2000 psi. or 1 week at 120°F. The latter condition was chosen because of its use in accelerated aging shrinkage tests and the values obtained probably include some primary creep, although the samples were unloaded before changing from 120°F. to 70°F. for recovery. The first Safety Aerographic Film base (AP-311), which was rather highly plasticized, had an undesirably high plastic flow as indicated in Table II. However, the present acetate butyrate Aerographic base (AB-284) is much better in this respect, although it is inferior to the high acetyl acetate (HA-411), which approaches more closely to the nitrate. Plastic flow can be reduced in topographic aerial film by keeping all tensions at a minimum, particularly when the film is wet or is at elevated temperatures. Unfortunately, dimensional changes resulting from plastic flow can also be caused by compressive forces exerted by the emulsion on the base and by the stress produced in winding. These effects are not so easily eliminated, as will be seen in later sections.

Folding Endurance and Tearing Resistance

The folding endurance of film base has been determined by means of the Schopper machine, and the tearing resistance by the Elmendorf tester. Both of these instruments are standard in the paper industry.⁵ In the folding test a sample of film base is bent sharply back and forth upon itself until it breaks. The number of double folds which the base withstands before rupture is the measure of its folding endurance. In the tear test, specimens are clamped in the instrument and a tear started with a knife. A weighted disc then revolves in such a manner as to give the energy required to continue the tear, from which the tearing force is calculated.

The folding endurance and tearing resistance of each Safety and Nitrate Aerographic Film base is recorded in Table II. It may be seen that the safety materials are somewhat inferior to the nitrate in both these characteristics. This disadvantage has been unavoidable in order to gain the other marked advantage of the safety base. The folding endurance and tearing resistance of film base im-

⁴ The term *plastic flow* is sometimes used to include both the recoverable and nonrecoverable portions of creep, but we have applied it throughout only to the nonrecoverable creep.

⁵ See "Standard Methods of Test for Folding Endurance of Paper," A.S.T.M. D643-43, and "Standard Method of Test for Internal Tearing Resistance of Paper," A.S.T.M. D689-44.

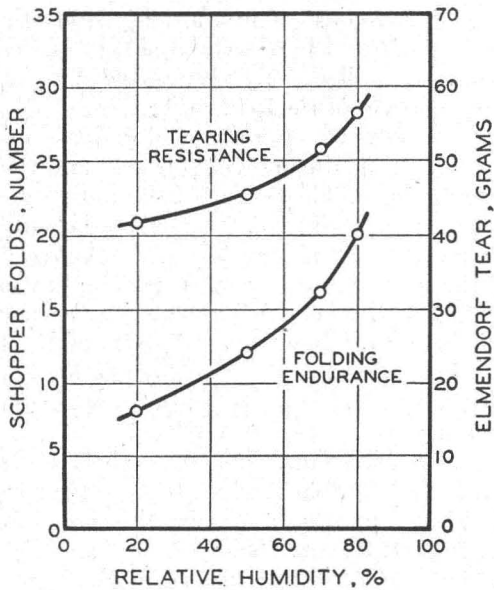


FIG. 11. The effect of relative humidity on the folding endurance and tearing resistance of Kodak Safety Aerographic Film base (Type AB-284) at 70°F.

the base from stretching. Film is more brittle when bent emulsion side out than when bent emulsion side in, because in the first case the emulsion itself is more likely to crack and localize the stress. Film is also more easily broken under adverse atmospheric conditions if bent rapidly than if bent slowly, because there is less time for elastic or plastic deformations to occur which tend to dissipate the stress.

The brittleness test which has been employed for Aerographic films in recent years was adapted from one originally designed by the Army Air Forces' Photographic Laboratory at Wright Field, Dayton, Ohio. Small loops of film emulsion side out are conditioned at 14% R.H. at 70°F., and placed between the jaws of a vise which is closed slowly and at a constant rate of speed (Figure 12). The distance between the jaws of the vise at the instant of fracture is read from a dial gage to 0.001", which is taken as a measure of the brittleness of the film. The minimum brittle point corresponds to double the film thickness, approximately .0125". This test is required by the present Army-Navy specification for aerial film (18), the maximum average brittleness allowed being 0.100" jaw separation at 14% R.H.⁶

The "vise brittleness" of various Aerographic films at 14% R.H., 70°F., is recorded in Table III. As in the case of other mechanical properties, the safety films are somewhat inferior to the nitrate, although considerable improvement has been made since the first Safety Aerographic Film, AP-311. (Data for the latter are unavailable because the vise brittleness test was not in use at the time this film was being manufactured.) Here it should be stated that the brittleness of a photographic film depends to a large extent on the mode of manufacture as well as on the chemical composition of the base.

The effect of relative humidity on the brittleness of Aerographic films (Figure 13) is extremely important. Above about 35% R.H. Safety Aerographic

prove with increase in relative humidity (Figure 11) and with increase in temperature. This means that the danger of tearing film can be greatly minimized by avoiding low relative humidities such as occur in all heated buildings in winter as well as in many natural climatic conditions. A relative humidity of about 50% is recommended for the handling of aerial negatives and air conditioning should be employed where necessary to maintain the humidity.

Brittleness

Brittleness in photographic film is seldom encountered at moderate relative humidities and normal room temperature, but may cause trouble in a very dry or a very cold atmosphere. Emulsion coated film is more brittle than the uncoated base because the adhesion of the emulsion tends to prevent the outer surface of

⁶ See appendix for details of brittleness test as specified.



FIG. 12. Testing Safety Aerographic Film for "vise brittleness."

Film will not break in the vise brittleness test, but as the relative humidity is reduced the brittleness increases, the curve rising very sharply below 20% R.H., in fact, the brittleness of film is so sensitive to small changes in relative humidity near 14% R.H. (the humidity specified by the Army-Navy test) that it is often difficult to distinguish a change in the product from an error in humidity. Aero-graphic film, although somewhat brittle at very low relative humidities, can be used satisfactorily at 20% R.H. or even lower if handled with care. However, the advantage of avoiding such conditions wherever possible is readily apparent from Figure 13 and is another argument for the use of air conditioned laboratories.

The effect of low temperatures on the brittleness of aerial film is of interest because of the temperatures encountered in cameras at high altitudes. Figure 14 shows the results of brittleness tests at temperatures down to -40°F . made on

Safety Non-Topographic (reconnaissance base) Aero Film. These tests were made during the war when there was more interest in this type of film, but the results would be very much the same for Aerographic film. For the tests at sub-zero temperatures it was necessary to precondition the film loops to the desired relative humidity at 70°F., seal them in small metal containers, and then cool to the desired temperature. The tests were then made quickly (in less than a

TABLE III. THE APPROXIMATE BRITTLINESS AND CURL OF KODAK SAFETY AND NITRATE AEROGRAPHIC FILMS (All tests made at 70°F.)

Designation	N-045	AP-311	AB-244	AB-284	HA-411
Type of Base	Nitrate	Acetate Propionate	Acetate Butyrate	Acetate Butyrate	High Acetyl Acetate
Date of Manufacture	1940-43	1937-40	1941-42	1943-47	1946
Vise Brittleness at 14% R.H. (average), inches.	0.034	—	0.054	0.073	0.051
Curl, $\frac{100}{R}$ inches*					
20% R.H.	122	238	167	189	153
50% R.H.	28	103	47	64	52
70% R.H.	3	23	5	14	7
Curl amplitude, 20% to 70% R.H.	119	215	162	175	146

* R = radius of curvature in widthwise direction.

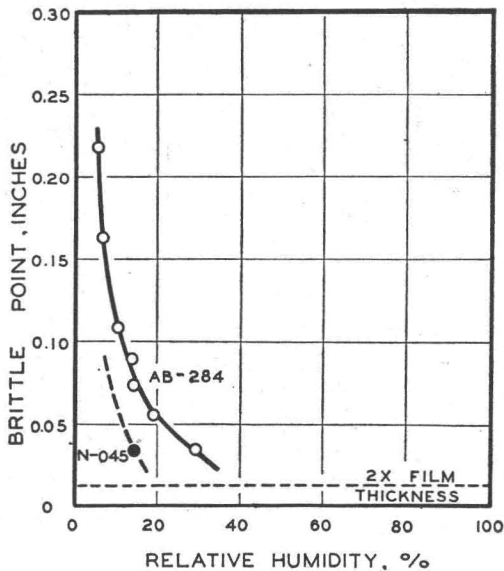


FIG. 13. The effect of relative humidity on the vise brittleness of Kodak Safety (AB-284) and Nitrate (N-045) Aerographic Film at 70°F.

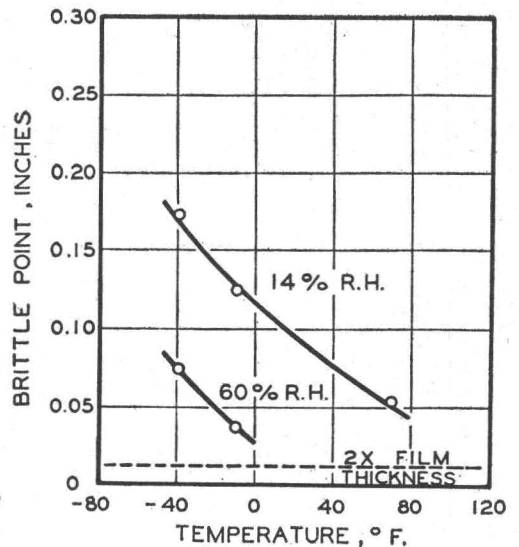


FIG. 14. The effect of temperature on the vise brittleness of Kodak Safety Non-Topographic Aero Film (Type AB-244 base).

minute) in a cold room where the humidity was not controlled. The data demonstrate that, although the brittleness of the film increases at very low temperatures, moisture apparently continues to exert its plasticizing action well below the freezing point. For example, the film exhibits about the same degree of brittleness at -25°F . and 60% R.H. as at 70°F . and 14% R.H. Film should be handled more carefully at subzero temperatures and precautions should be taken to prevent any loss of moisture from the film as supplied by the manufacturer. (Aerographic film is in equilibrium with air at 50% to 60% R.H. when packed.) Where possible, film equipment to be used at low temperatures should be designed so as to minimize film accelerations, eliminate small radii of curvature, etc.

Curl

Aerial photograph c film curls because the emulsion has a coefficient of humidity expansion about 8 times that of the base (4), but since the two are firmly attached together the emulsion must of necessity pull the base into a curved shape as the relative humidity decreases. Curl is also affected by plastic flow when the film is wound in roll form. The mechanism of curl and the influence of a number of variables on curl have been described previously in connection with motion picture film (4) and the same principles apply to the curl of aerial film.

It has been customary to measure the curl of Aerographic film by taking 5 foot lengths from a standard $5\frac{1}{4}$ " or $9\frac{1}{2}$ " roll and after conditioning the samples at the desired relative humidity, the curl in the widthwise direction is measured. This is done by laying the film on a flat table and measuring the height of the edges of the film above the table if the curl is moderate; or by measuring the chord separating the edges, or the diameter of the tube formed by the film if the

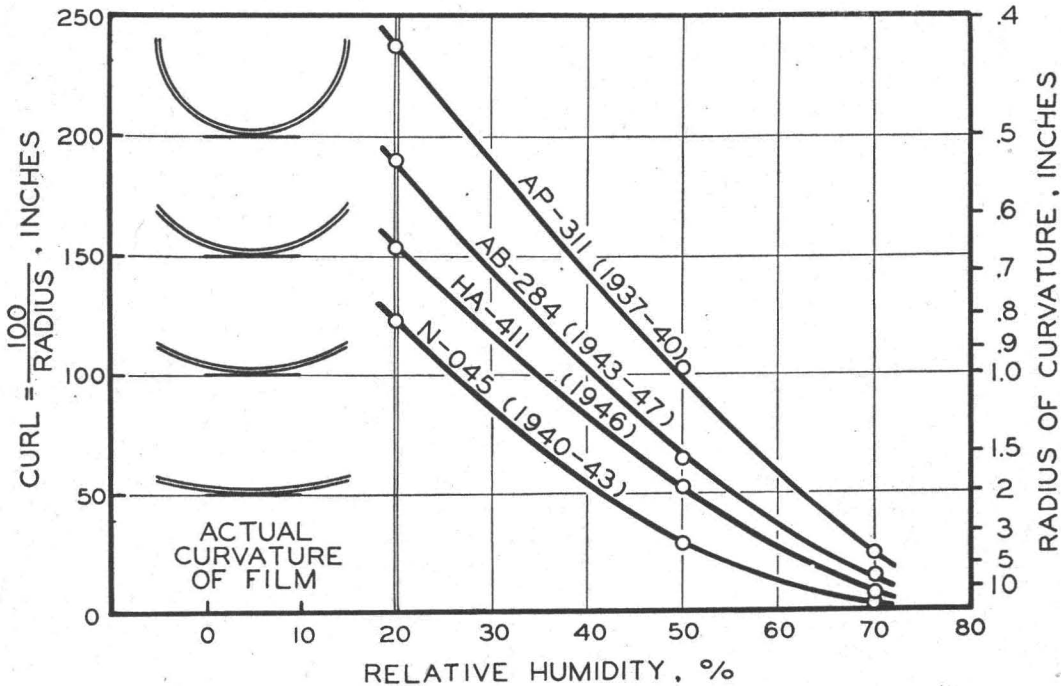


FIG. 15. The effect of relative humidity on the curl of various Kodak Safety (AP-311, AB-284, HA-411) and Nitrate (N-045) Aerographic Films at 70°F .

curl is severe. For convenience, the data have been converted to radius of curvature and then calculated as 100 times the reciprocal radius to obtain an index which increases as the curl becomes greater.

The curl of the various Safety and Nitrate Aerographic Films at 20, 50 and 70% R.H. at 70°F. is recorded in Table III. The difference between the curl at 20% R.H. and the curl at 70% R.H. sometimes called the humidity curl amplitude, is an important property of any photographic film. The safety films have a higher humidity curl amplitude than the nitrate because the supports have a lower modulus of elasticity (cf. Table II), that is, less rigidity or stiffness. The softer the base, the more easily it is pulled by the emulsion into a curved shape. For this reason, the present acetate butyrate Safety Aerographic Film (AB-284) is lower in curl than the first Safety Aerographic Film (AP-311), and the high acetyl acetate (HA-411) is lower still.

The effect of relative humidity on curl is shown more clearly by the curves in Figure 15. The arcs of circles on the left hand side of the diagram illustrate the actual degree of curl (1:1 scale) for different values of the curl index and the radius of curvature. All of the films increase in curl as the relative humidity is reduced because of the increased contraction of the emulsion. Figure 15 demonstrates once more the marked advantage of handling aerial negatives in an atmosphere controlled at about 50% R.H. (A relative humidity of 70% would be still better in so far as minimizing curl is concerned, but is undesirably high for reasons discussed in other sections.)

V. DIMENSIONAL STABILITY

The dimensional changes which occur in any photographic film with changes in humidity, temperature, age, and handling are extremely complex, and are the result of a number of different effects. The most important of these may be classified as follows:

- A. Temporary or reversible dimensional changes
 1. Humidity expansion and contraction.
 2. Thermal expansion and contraction.
- B. Permanent or irreversible dimensional changes
 1. Loss of residual solvent or volatile material other than moisture.
 2. Plastic flow.
 3. Release of mechanical strain.

The nature of most of these dimensional changes has been described previously in connection with motion picture film (4) and the same principles apply to aerial film. The reversible expansion and contraction of film with change in relative humidity and temperature, and the permanent shrinkage from loss of residual solvents in the base are well understood. Plastic flow may be caused either by the contractive force exerted by the emulsion on the base at low relative humidities, or by tension in handling or processing. Mechanical strain, or delayed elastic deformation, may be present in film base if it is stretched under certain conditions during manufacture and then cooled before the strain is released. If such strain is present, it may be released at some later time during the life of the film, with a consequent lengthwise shrinkage and widthwise expansion. In addition to the above types of film shrinkage there are a number of dimensional phenomena of relatively small magnitude (such as hysteresis) which are not as well understood. These are unimportant in most kinds of photographic work, but even the smallest dimensional change must be considered in the case of topographic aerial film. All of the various types of temporary and permanent dimensional change may occur simultaneously, so that the dimensions of a piece of film at any instant are the result of many factors which are often difficult to predict.

The residual solvent content of the present Aerographic film base (AB-284) is so low as to be virtually negligible. Consequently, loss of solvent from the base, which is the prime cause of permanent shrinkage in many types of photographic film, is relatively unimportant here. Mechanical strain which can be released under any practical storage condition has also been reduced to a very low level in the manufacturing operation. For these reasons plastic flow is relatively more serious as a source of permanent dimensional change in Aerographic film. All types of permanent shrinkage are increased by heat so that elevated temperatures during storage should be avoided wherever possible.

The importance of good uniaxialism in topographic aerial film has already been mentioned. If there is any orientation of the cellulose ester molecules in the base in the machine direction, humidity and thermal expansion or contraction will be greater widthwise than lengthwise, which will cause (image) distortion⁷ in the negative. For this reason a high degree of uniaxialism in the base must be maintained by the film manufacturer.

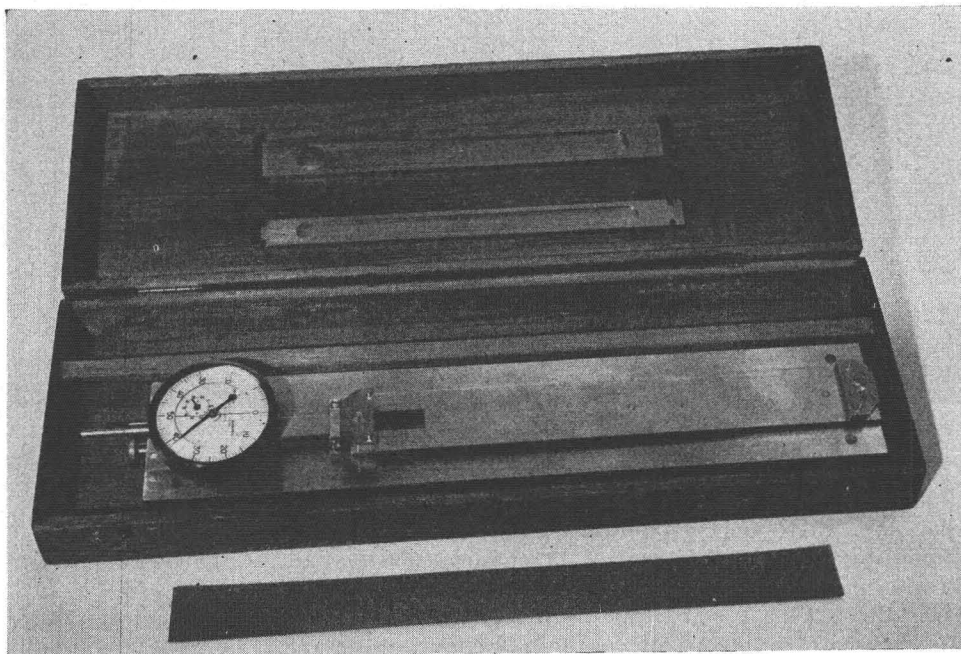


FIG. 16. The "pin-gage" used for measuring film shrinkage.

Shrinkage Testing Methods

A number of film shrinkage tests, some of which were described by Carver (1), have been developed both for manufacturing control and for experimental purposes. A "pin-gage" similar to that described by Davis and Stovall (2) is used in the majority of our shrinkage work. Strips of film or film base 35-mm. \times 15 inches long are punched to provide two pairs of standard 35-mm. perforations ten inches apart which fit four pins on the instrument (Fig. 16). Two of the pins are fixed and two are attached by means of an arm to a dial gage graduated in 0.001 inch divisions. Standard gage bars are used to check the zero point of the

⁷ The term "distortion" is used throughout this paper to signify unequal expansion or shrinkage in the length and width directions of the film, and not irregular deformations such as buckle.

instrument. For special problems where shrinkage measurements are desired on actual aerial film rolls, 17.5 cm² grids are exposed on the film from a glass plate negative of accurately known dimensions. The distance between the grid lines on the film is measured both lengthwise and widthwise with an optical gage after development (Fig. 17). The illuminator employed for this purpose contains fluorescent bulbs and is well ventilated to prevent the film from becoming heated.

Of the utmost importance in studying film shrinkage is the control of the laboratory temperature and relative humidity, and considerable effort has been

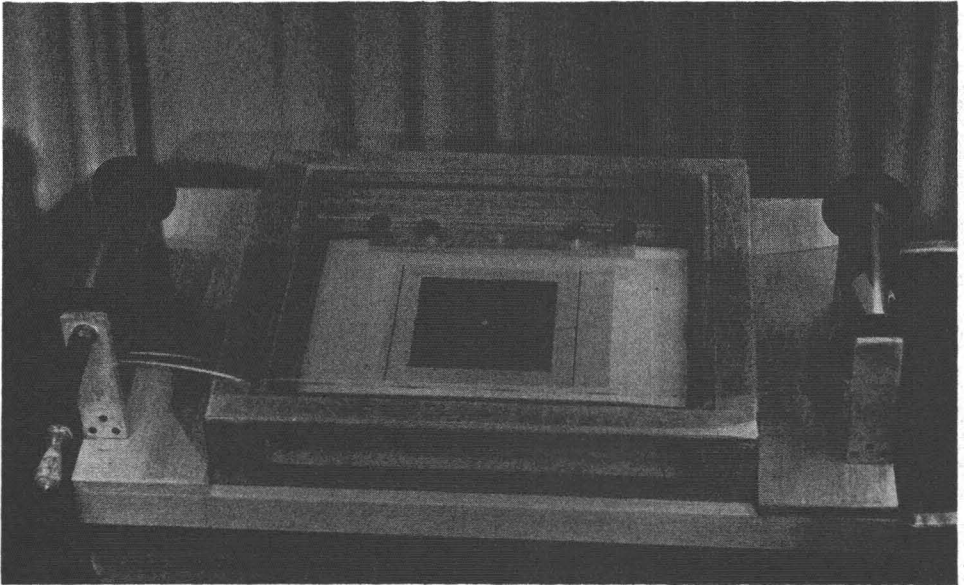


FIG. 17. Apparatus for measuring shrinkage of aerial film rolls.

expended to secure accurately and automatically controlled air conditioned work space. Several rooms each controlled at a different constant relative humidity are in continual use for this purpose. The variation in conditions from one position to another in the room, or the variation with time, is held within $\pm 1\%$ to $\pm 2\%$ R.H. and $\pm 1^\circ\text{F}$. This has been achieved by advanced instrumentation and by constant surveillance. Film samples are conditioned several hours at a standard humidity and temperature (generally 50% R.H., 70°F.) before each measurement.

The instrument error in measuring the dimensions of a piece of film with the pin-gage is approximately $\pm 0.005\%$ of the dimension for a single observation. However, shrinkage is the difference between an initial and final reading, the errors for which may be additive. Another source of error is the small variation in atmospheric conditions which occurs in spite of automatic controls. In tests which involve a variety of storage or conditioning treatments these errors also accumulate. To minimize such errors, two to five strips or grids are tested from each sample of film and standard film checks or controls are always included in each experiment. Absolute errors in tests made at different times do not normally exceed $\pm 0.03\%$ and the relative errors between two sets of samples tested together are approximately $\pm 0.01\%$ of the dimension.

The shrinkage tests employed for Aerographic films include the following:

A. Tests Made on the Film Base

1. *Swell in Water*—Sometimes called the "Swell and Shrink Amplitude Test" (1). In this test, strips of film base are alternately soaked 30 minutes in 125°F. water and measured wet, then dried 60 minutes in a 125°F. oven and measured dry. This cycle is repeated (usually three times) until constant values are obtained. The percent swell is calculated from the difference between the final wet and dry measurements. This is a test for reversible dimensional change, and the magnitude of the swell indicates the moisture resistance of the base. The difference between the lengthwise and widthwise swell in water gives a measure of uniaxialism and is an index of the image distortion which may be expected from thermal or moisture dimensional changes.

2. *Waterbath Shrinkage*—Samples of film base are conditioned at 70°F., 50% R.H., measured, then soaked for 17 hours in 100°F. water, reconditioned at 70°F., 50% R.H. and remeasured. The difference between the two readings is the waterbath shrinkage which is a measure of permanent shrinkage caused by either residual solvent or mechanical strain. The values obtained cannot be translated directly into terms that would be of use in practice, but the test is of value for control purposes.

B. Tests Made on the Finished Film

1. *Humidity Expansion*—Samples of film are conditioned and measured, first at 20% R.H., then at 70% R.H. at 70°F. The difference between the two measurements is called the humidity amplitude, from which the coefficient of humidity expansion per 1% R.H. may be calculated.

2. *Thermal Expansion*—The expansion and contraction of film with change in temperature is measured under such conditions that moisture changes are eliminated. (See section on thermal expansion for details.)

3. *Processing Shrinkage*—Film strips are conditioned at 70°F., 50% R.H., then tray developed, fixed, washed, dried and reconditioned at 70°F., 50% R.H. and remeasured. The difference between the two measurements is the processing shrinkage.

4. *Accelerated Aging Shrinkage*—Sometimes called the "Special Development Shrinkage Test" (1). Film strips are conditioned at 70°F., 50% R.H., measured, tray processed, aged for 7 days at 120°F., 20% R.H., then reconditioned at 70°F., 50% R.H. and remeasured. The difference between the two measurements is the accelerated aging shrinkage. Topographic aerial film must have an average length and width shrinkage not exceeding 0.15% and a length and width shrinkage difference not exceeding 0.07%, by this test to pass the present Army-Navy specification (18).⁸

5. *Long-Time Aging Shrinkage*—Tests of this type are conducted in the same manner as the accelerated aging shrinkage test, except that any aging condition of temperature, humidity and time may be substituted for the accelerated condition of 7 days at 120°F. 20% R.H.

Some modifications have been made in the details of these tests in recent years to improve their accuracy and reproducibility. In particular, a preconditioning procedure has been employed for several years for all permanent shrinkage tests to reduce errors caused by hysteresis. Prior to each measurement at the standard condition of 70°F., 50% R.H., the film specimens are preconditioned at 70°F., 20% R.H. so that the final humidity is always approached from the low side regardless of the aging condition. In the majority of control tests, the conditioning time is, of necessity, limited to two to three hours, in which time practical equilibrium is reached (cf. Figure 5). However, the conditioning time for the accelerated aging test was increased to 24 hours about a year ago in an effort to improve its reproducibility.

Shrinkage Control in Production

In all industrial operations certain manufacturing tolerances are unavoidable and the production of photographic film base is no exception. Although the manufacturing process has no effect on the magnitude of the humidity and thermal expansion once the most suitable cellulose ester and dope formulation have been selected, the uniaxialism and permanent shrinkage can be varied within certain limits. In Aerographic base these are held as close as possible to the optimum value by an elaborate system of control testing.

Although tests on the finished product (emulsion coated film) are necessary, our primary shrinkage control is maintained on the film base itself by means of

⁸ See appendix for details of accelerated aging shrinkage test as specified.

the swell in water and waterbath shrinkage tests. The reason for this is not only the unavoidable delay between manufacture of the base and coating the emulsion, but because we have found tests on the base to be more dependable for shrinkage control. This is largely the result of complicating factors introduced by the emulsion in the accelerated aging test, which have nothing to do with the manufacture of the base. (In a later section this point is discussed more fully.) Natural aging tests up to a year are then run on the finished film whenever a manufacturing modification is made to ensure that the control tests on the base are correctly interpreted.

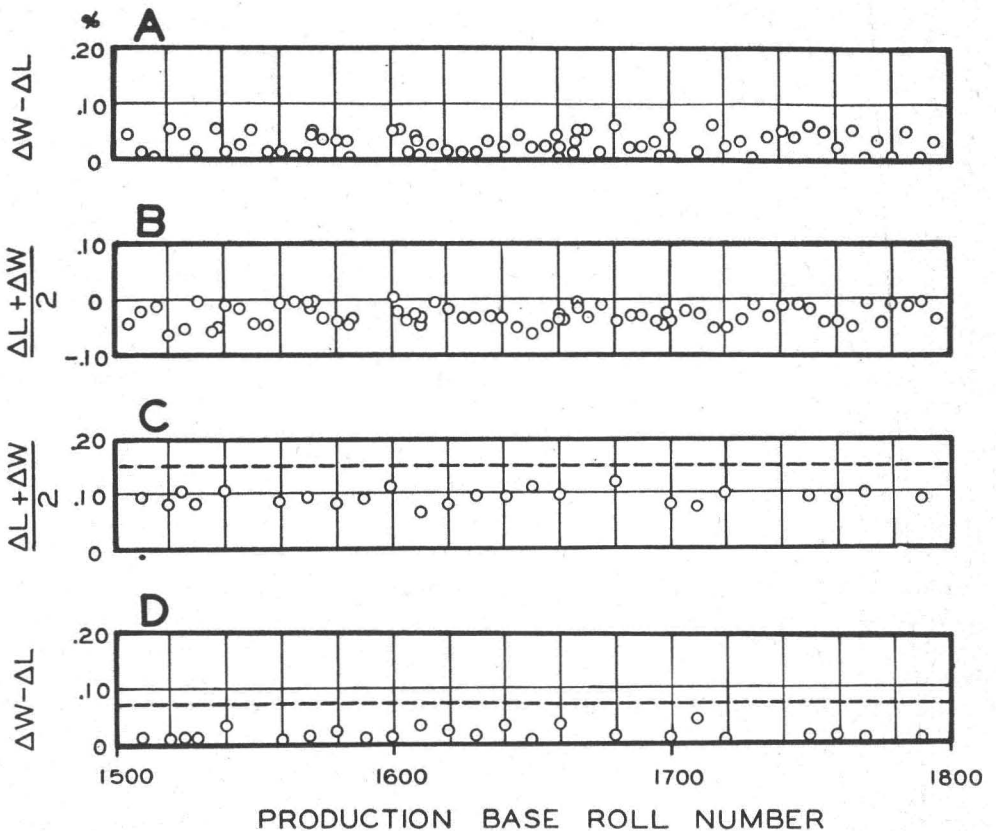


FIG. 18. Typical control charts showing percent change in dimension for Kodak Safety Aerographic Base and Film in routine production testing. A, differential swell in water of base; B, average length and width waterbath shrinkage of base (a negative shrinkage indicates a swell); C, average length and width accelerated aging shrinkage (7 days 120°F., 20% R.H.) of film; D, differential accelerated aging shrinkage of film.

Figure 18 illustrates the type of control chart maintained for each casting machine making Aerographic film base, the points representing individual production rolls. The difference between the length and width swell in water (A, Fig. 18) theoretically should be zero and it has been possible in practice to come very close to this ideal. The width minus length differential swell in water of both Safety and Nitrate Aerographic film base is generally under 0.06% and has been held as low as 0.03% for relatively long periods of time. This may be compared with values up to 0.20% or even 0.40% for the differential swell of Non-Topographic Aero Film base.

It has been found by experience that the average of the length and width waterbath shrinkage (B, Fig. 18) which may vary up to 0.5% to 1.5% for some types of photographic film base, should be zero or less (i.e., an expansion) for Aerographic film support. (The apparent permanent expansion recorded in this test is largely the result of hysteresis errors which are constant and unimportant as long as the details of the test procedure are standardized.) Figure 18 also illustrates the average shrinkage (C) and the length and width shrinkage difference (D) for the accelerated aging test. The broken lines indicate the limits set by the present Army-Navy specification (18).

Humidity Expansion

The humidity expansion of the present Safety Aerographic Film (AB-284) base) is approximately 0.40% between 20% and 70% R.H. at 70°F., which is equivalent to a coefficient of expansion of 8×10^{-5} per 1% R.H. The test method described above for determining the humidity expansion of film does not correct for errors caused by hysteresis, since 20% R.H. is approached from the high side and 70% R.H. from the low side. Experiments have shown that if both humidities are approached from below to eliminate hysteresis, the humidity expansion of Aerographic film is about .03% higher over the 50% range in relative humidity employed. This error is not important in determining humidity coefficients over a wide range of relative humidity, but hysteresis may be a source of error in practical measurements under certain conditions.

It is of interest to note here that the coefficient of humidity expansion for film is appreciably greater than that for the base alone. This is because the base is wet by the emulsion during coating and the two layers are in dimensional equilibrium at high relative humidities. After drying, the emulsion tends to contract much more than the base when the relative humidity is reduced, as discussed in the section on curl. Since the emulsion is firmly attached to the base, the latter is compressed which increases the coefficient of humidity expansion of the film beyond that of the base alone. For the same reason, Safety Aerographic Film has a slightly higher humidity coefficient of expansion than Nitrate Aerographic Film even in cases where the swell in water of the safety base is lower. This is because the safety base has a somewhat lower modulus of elasticity or stiffness (cf. Table II), and is thus compressed more than nitrate base by the emulsion at low relative humidities.

Another question that is sometimes raised in regard to the humidity expansion of film is the variation of the coefficient at different relative humidity levels. This is illustrated in Figure 19, which shows humidity expansion versus relative humidity curves for Safety Aerographic Film on the older acetate butyrate base (AB-244) between 10% and 80% R.H. These curves are very nearly linear be-

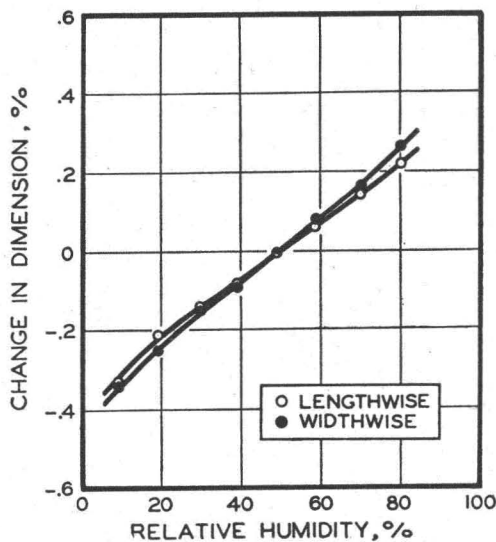


FIG. 19. The change in dimension of Kodak Safety Aerographic Film (Type AB-244 base) at various relative humidities at 70°F.

tween 20% and 70% R.H. but slightly steeper above and below these limits. However, the change in slope above 70% R.H. is not as great as with the corresponding curve for equilibrium moisture content (Figure 4).

The rate at which a film attains dimensional equilibrium when the ambient relative humidity is changed is important in many practical problems. The rate of conditioning of Safety Aerographic Film from one humidity to another, measured by change in weight, has been described in connection with Figures 5 and 6. To determine the rate of change of dimension, strips of film were thoroughly conditioned at a low relative humidity and then measured at various intervals of time after moving to air at a high relative humidity. The results of two such tests, one between 20% and 50% R.H. and the other between 10% and 70% R.H., are plotted in Figure 20. A similar curve for topographic aerial film taken

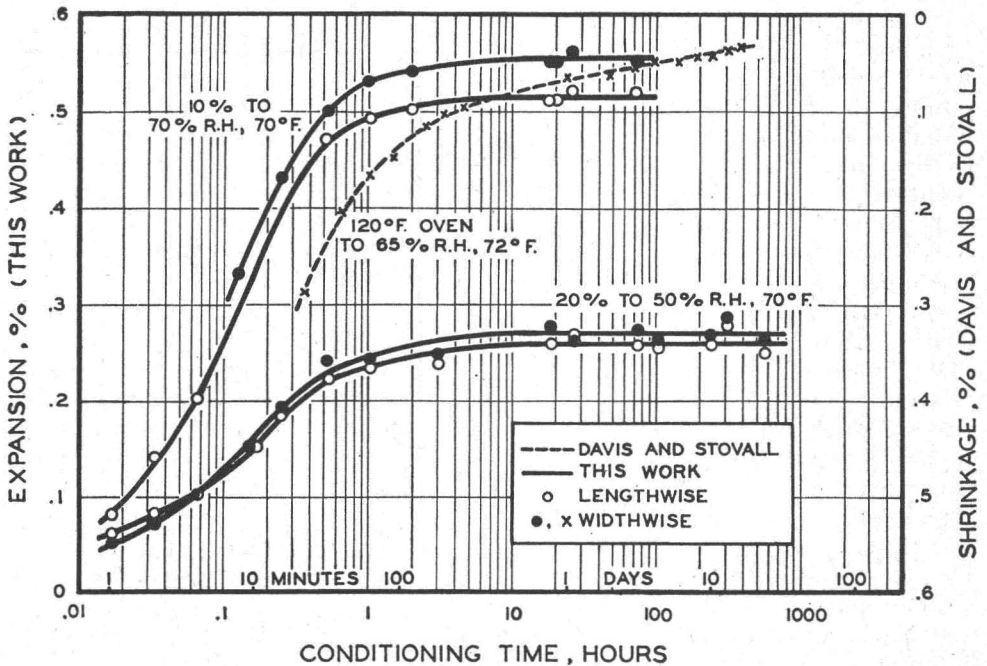


FIG. 20. The rate of change of dimension of aerial film from one relative humidity to another. (Davis and Stovall, nitrate topographic aerial film; this work, Kodak Safety Aerographic Film, Type AB-284 base.)

from the data of Davis and Stovall (2) is also included in Figure 20, replotted to the same scale.

Davis and Stovall point out that in their experiments dimensional equilibrium was not reached even after two weeks' conditioning and that about 100 days would be required. In the present experiments, dimensional equilibrium was reached in a few hours, lagging perhaps slightly behind moisture equilibrium (cf. Figures 5 and 20). However, it is believed that this apparent disagreement can be reconciled. In the experiments of Davis and Stovall the film was dried for 48 hours in an oven at 120°F. before starting the test. This treatment would cause compression of the base under the contractive force of the emulsion. Subsequent exposure to air at 65% R.H. at room temperature might be expected to result in partial recovery of the delayed elastic deformation (cf. Figure 10). This effect would result in a slow expansion (which is in the right direction to account for the observed behavior), entirely separate from the normal humidity expan-

sion. The present data indicate that with ordinary changes in humidity, dimensional equilibrium is reached in several hours, which is fortunate from a practical point of view.

Thermal Expansion

Thermal expansion is seldom important with most types of photographic film, even where good dimensional stability is needed. This is partly because the coefficient of thermal expansion for photographic film per 1°F . is only about one-half the coefficient of humidity expansion per 1% R.H. Ordinary room humidities also vary over a much wider range than normal room temperatures. Another reason is that the relative humidity generally decreases as the temperature increases (or vice versa) and these two effects partially compensate each other. However, in the case of topographic aerial photography where cameras may be exposed to very low temperatures at high altitudes, thermal expansion or contraction of the film becomes much more serious.

The accurate determination of the coefficient of thermal expansion of photographic film is difficult because it is not easy to control or even measure the relative humidity of air at low temperatures. In the method we have adopted, strips of film about 0.6×11 inches are conditioned at 70°F ., 50% R.H. and then sealed between a pair of glass plates by wrapping two layers of a rubber base adhesive tape around the edges. Separators are left between the plates to prevent any pressure on the specimens. The distance between two gage marks on the strip of film is then read through the glass at the desired temperature by means of a pair of shop microscopes mounted ten inches apart on a steel bar. (A correction is made for the thermal expansion of the steel bar.) The volume of the free air space between the glass is only about 1.0 cc. so that any interchange of moisture between the film and the air is negligible. In this way, the temperature can be varied without any significant change in the moisture content of the film. The temperature range usually covered in these determinations is from -10°F . to 90°F .

The thermal coefficient of linear expansion for Safety Aerographic Film determined in the above manner is approximately 4×10^{-5} per $^{\circ}\text{F}$., and increases slightly with increase in temperature and with increase in the moisture content of the film. The values reported here agree well with those quoted by P. D. Carman from a wartime report of the British Ministry of Aircraft Production (5) for the coefficient of thermal expansion of Safety Aerographic Film at 75% R.H. (average, 7.7×10^{-5} per $^{\circ}\text{C}$. or 4.3×10^{-5} per $^{\circ}\text{F}$.). By way of comparison, the

TABLE IV. CORRELATION BETWEEN DIFFERENTIAL THERMAL EXPANSION AND DIFFERENTIAL SWELL IN WATER FOR KODAK SAFETY AEROGRAPHIC FILM BASE

Type AB-284 Base	Untreated Control	Sample Stretched Lengthwise at 290°F . (loss of width = 15%)
1. Swell in water, %		
Lengthwise	0.70	0.44
Widthwise	0.71	0.78
Difference	0.01	0.34
2. Thermal Coefficient of Expansion per $^{\circ}\text{F} \times 105$.		
Lengthwise	3.4	1.9
Widthwise	3.4	4.2
Difference	0	2.3

coefficient of thermal expansion of crown glass of the type used in photographic plates is about 0.5×10^{-5} per $^{\circ}\text{F}$., or roughly one-tenth that of film.

It is worth noting here that a close correlation exists between the width minus length differential thermal expansion of film base and the width minus length differential swell in water (Table IV). When the cellulose ester miscelles in the base are partially oriented in the machine direction, an increase in either thermal agitation or moisture content evidently increases the separation between the particles more in the widthwise than in the lengthwise direction. This is another reason why topographic aerial film base must be as uniaxial in structure as possible.

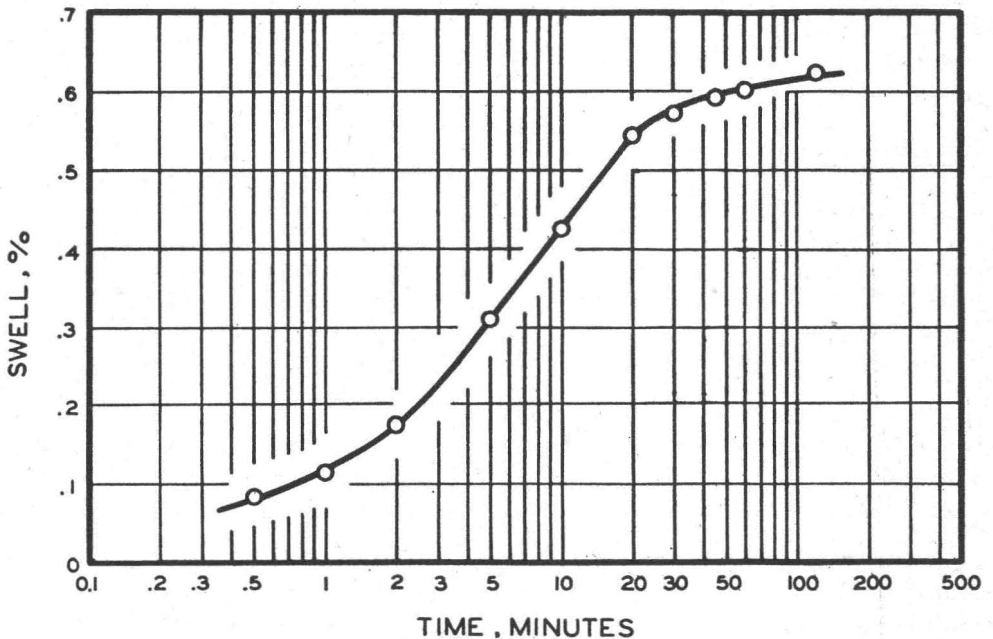


FIG. 21. The rate of swell of Kodak Safety Aerographic Film (Type AB-284 base) in water at 70°F . Film initially in equilibrium with air at 50% R.H., 70°F .

Processing and Aging Shrinkage

All photographic films tend to shrink slightly in processing and to continue shrinking slowly thereafter at a rate which depends on the type of film and the storage conditions. The net shrinkage of Aerographic film which occurs in processing does not normally exceed 0.02% to 0.04%. This, of course, assumes that the film is allowed to reach complete equilibrium with air at the same temperature and relative humidity before and after processing and that hysteresis is eliminated. Actually these conditions are seldom met in practice and the change in dimension on processing may be zero or slightly positive because of hysteresis, even when humidity or thermal expansion or contraction are absent.

The rate of swell of aerial film during processing is sometimes of interest in the design of continuous processing machines. Data on this point are provided in Figure 21, which shows the rate of swell of Safety Aerographic Film (AB-284 base) in 70°F . water. The effect of several processing variables such as tension, drying temperature, alcohol drying, etc., on the dimensional stability of Safety Aerographic Film is discussed in Section VI.

After processing, the aging shrinkage of the present Safety Aerographic Film (AB-284 base) when stored in flat sheets open to the air for a year at temperatures up to 120°F. amounts to only about 0.05%. The total shrinkage including the processing shrinkage, therefore does not normally exceed 0.1% in a year. This may be compared with a shrinkage of 1.0% or more for other types of photographic film stored under the same conditions. Most of the aging shrinkage of AB-284 occurs in the first month or two, the time-shrinkage curve thereafter remaining virtually flat. Under the same storage conditions the length minus width differential shrinkage is only about 0.01% to 0.02%. If the film is stored open to the air under humid conditions, particularly at temperatures above 70°F., hysteresis will cause a semi-permanent expansion which remains even after the film is returned to a standard condition, such as 70°F., 50% R.H. A comparison of the aging shrinkage of various Safety and Nitrate Aerographic Films and the effect on dimensional stability of storing film in roll form is given in the following sections.

Comparison of Various Aerographic Films For Dimensional Stability

The approximate shrinkage characteristics of the different Safety and Nitrate Aerographic Films manufactured in the last ten years are recorded in Table V. Several other films are also included in the table for comparison purposes. (The chemical composition and moisture absorption of the respective cellulose esters employed may be found by reference to Table I.) The A-104 film base listed in Table V was made experimentally from a regular acetone-soluble cellulose acetate in such a manner that it would have the best topographic shrinkage properties possible to obtain with this type of ester, but it was never used for Aerographic film. Data on the shrinkage of Safety and Nitrate Non-Topographic Aero Film are also given in Table V for comparison. These films were used during the war (the nitrate in England) for reconnaissance purposes, where a high degree of uniaxialism, and low permanent shrinkage is not essential.

It is necessary to give a brief history of each of the four types of Safety Aerographic Film before comparing their dimensional stability.

Type AP-311 (Cellulose acetate propionate)—This was the first Safety Aerographic Film and is the same as that described by Carver in 1938 (1).⁹ AP-311 had good uniaxialism and low shrinkage at normal temperatures, but the base was softer than desired and subject to excessive plastic flow (cf. Table II).

Type AB-244 (Cellulose acetate butyrate)—This base was introduced in 1941 for Aerographic film because it was less susceptible to plastic flow than AP-311 and was also superior in other mechanical properties (cf. Table II). It was believed that AB-244 had as low permanent shrinkage as AP-311, but this did not prove to be the case. When long-time aging tests were completed it was found that AB-244 had a higher shrinkage than expected on the basis of accelerated aging tests. The situation was complicated by the fact that the urgent requirements of the Armed Services for Aerographic film during the early part of the war could not be met except by some increase in the casting speed which resulted in slightly poorer uniaxialism and a little higher shrinkage.¹⁰ Strenuous efforts were made to overcome these defects in the middle of many wartime production difficulties and an improved support formulation was soon developed. AB-244 was then restricted for nontopographic or reconnaissance use.

Type AB-284 (Cellulose acetate butyrate)—This film base was introduced at the beginning of 1943 and, although made from the same cellulose ester as AB-244, it proved to have the low long-time shrinkage and superior uniaxialism that was desired and approximately the same mechanical properties.

Type HA-411 (High acetyl cellulose acetate)—This type of Safety Aerographic base was

⁹ Minor discrepancies between the shrinkage values given here and those published in 1938 for AP-311 are due to the fact that more data were obtained after the earlier publication.

¹⁰ The production of Safety Aerographic Film in 1942 was 10-fold that in 1940 and the production of both Safety Aerographic and Non-Topographic Aero Film in 1942 was 20-fold that in 1940.

TABLE V. THE APPROXIMATE DIMENSIONAL CHARACTERISTICS OF VARIOUS KODAK AERO FILMS

Designation	Aerographic Base							Non-Topographic Base	
	N-025	N-045	A-104*	AP-311	AB-244	AB-284	HA-411	N-045	AB-244
Type of Base	Nitrate	Nitrate	Regular Acetate	Acetate Propionate	Acetate Butyrate	Acetate Butyrate	High Acetyl Acetate	Nitrate	Acetate Butyrate
Date of Manufacture	1936-39	1940-43		1937-40	1941-42	1943-47	1946	1941-44	1941-45
Direction of Test**	L W D	L W D	L W D	L W D	L W D	L W D	L W D	L W D	L W D
Film Base									
(1) Swell in Water, % (reversible)	.55 .61 .06	.68 .73 .05	1.10 1.25 .15	.52 .55 .03	.50 .57 .07	.68 .72 .04	.83 .90 .07	.53 .73 .20	.43 .58 .15
(2) Waterbath Shrinkage, %*** (permanent)	-.07 -.12 .05	-.06 -.15 .09	.08 -.16 .24	.11 .03 .08	.03 -.03 .06	-.02 -.07 .05	.01 -.06 .07	.38 .43 .05	.19 .16 .03
Finished Film									
(1) Humidity Coefficient of Linear Expansion per 1% R.H. × 105 (20% to 70% R.H. at 70°F.)	6.2 7.0 0.8	6.4 7.0 0.6	10.0 11.5 1.5	8.0 8.4 0.4	7.0 8.0 1.0	8.0 8.4 0.4	7.8 8.4 0.6	5.4 7.2 1.8	6.0 7.6 1.6
(2) Thermal Coefficient of Linear Expansion per °F. × 105 (-10°F. to 90°F. at 50% R.H.)	2.9 3.1 0.2	3.0 3.2 0.2	4.4 5.0 0.6	4.2	3.4 3.7 0.3	4.2 4.4 0.2	3.0 3.2 0.2	2.6 3.8 1.2	3.0 4.0 1.0
(3) Processing Shrinkage, %		.02 .03 .01		.04 .03 .01	.05 .06 .01	.03 .04 .01	.03 .04 .01	.06 .09 .03	.06 .09 .03
(4) Accelerated Aging Shrinkage (Processing plus 7 days at 120°F., 20% R.H.), %	.13 .11 .02	.16 .13 .03	.14 .18 .04	.17 .12 .05	.13 .16 .03	.11 .10 .01	.10 .12 .02	.31 .41 .10	.25 .32 .07
(5) Long-Time Aging Shrinkage (Processing plus 1 year at 70°F., 50% R.H.), %		.06 .07 .01		-.02 .00 .02	.18 .21 .03	.09 .08 .01		.34 .48 .14	.34 .51 .17

* Regular acetate base type A-104 has never been used for Aerographic film. The data are included only for comparison.

** L = Lengthwise, W = Widthwise, D = Difference.

*** A negative shrinkage indicates a swell.

tried for several months in 1946, partly because of its advantages over AB-284 in mechanical properties (cf. Table II), and partly for manufacturing reasons. However, HA-411 proved to have slightly poorer uniaxialism than AB-284, and higher long-time shrinkage was feared. For this reason, AB-284 is still the standard base for Safety Aerographic Film.

The shrinkage characteristics of these different Safety Aerographic Films compared with nitrate are discussed more fully below under the sections uniaxialism, temporary expansion or contraction, and permanent shrinkage:

1. *Uniaxialism*.—The best measure of uniaxialism, or freedom from molecular orientation in film base is given by the width minus length differential swell in water. It should be noted that the best criterion of image distortion to be expected from poor uniaxialism in different types of base is the actual differential swell in water ($\Delta W - \Delta L$), and not the ratio $(\Delta W - \Delta L)/(\Delta L + \Delta W)_2$ which gives the relative degree of lengthwise orientation. In other words, one film base hav-

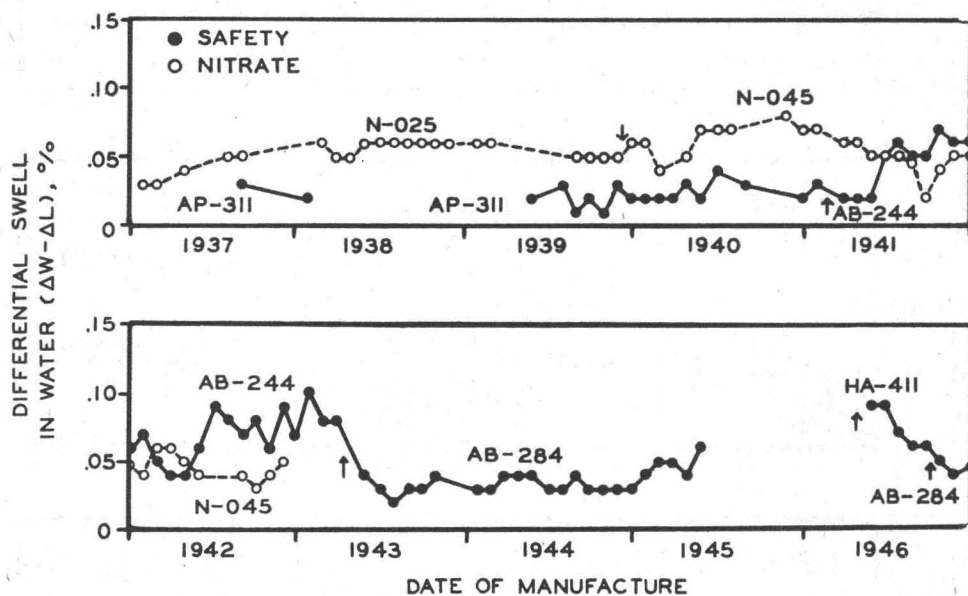


FIG. 22. Monthly average differential swell in water for all Kodak Safety and Nitrate Aerographic Film base manufactured from 1937 to 1946. (Arrows indicate support formulation changes.)

ing a higher over-all swell in water than another must have relatively less molecular orientation or the image distortion will be larger. This is another reason why a regular cellulose acetate is difficult to use for a topographic aerial film base.

The uniaxialism of each type of base as indicated by the width minus length differential swell in water is recorded in Table V, and the monthly average for all Aerographic base manufactured since 1937 is plotted in Figure 22. Up until the middle of 1941 the uniaxialism of the safety base was actually much better than that of the nitrate. However, during the early part of the war the differential swell in water of AB-244 did go higher than we like to have it because of the production difficulties mentioned above which existed at that time. In spite of this the differential swell in water of the poorest wartime Aerographic base was still very much less than that of Non-Topographic Aero base. With the introduction of AB-284 early in 1943 the differential swell in water was reduced to its previous low level where it remained during the balance of the war. The HA-411 Aerographic base manufactured for a short time in 1946 also had poorer

uniaxialism than AB-284 and the latter is still the standard Aero-graphic base at the present time.

2. *Temporary Expansion and Contraction.*—The swell in water of the different types of mixed cellulose ester Safety Aero-graphic Film base is just as low as that of the nitrate base and is much lower than that of the regular cellulose acetate base (A-104) as shown in Table V. However, the coefficient of humidity expansion of the corresponding emulsion coated films (AP-311, AB-244 and AB-284) is not quite as low as that of the nitrate films. This is because these safety

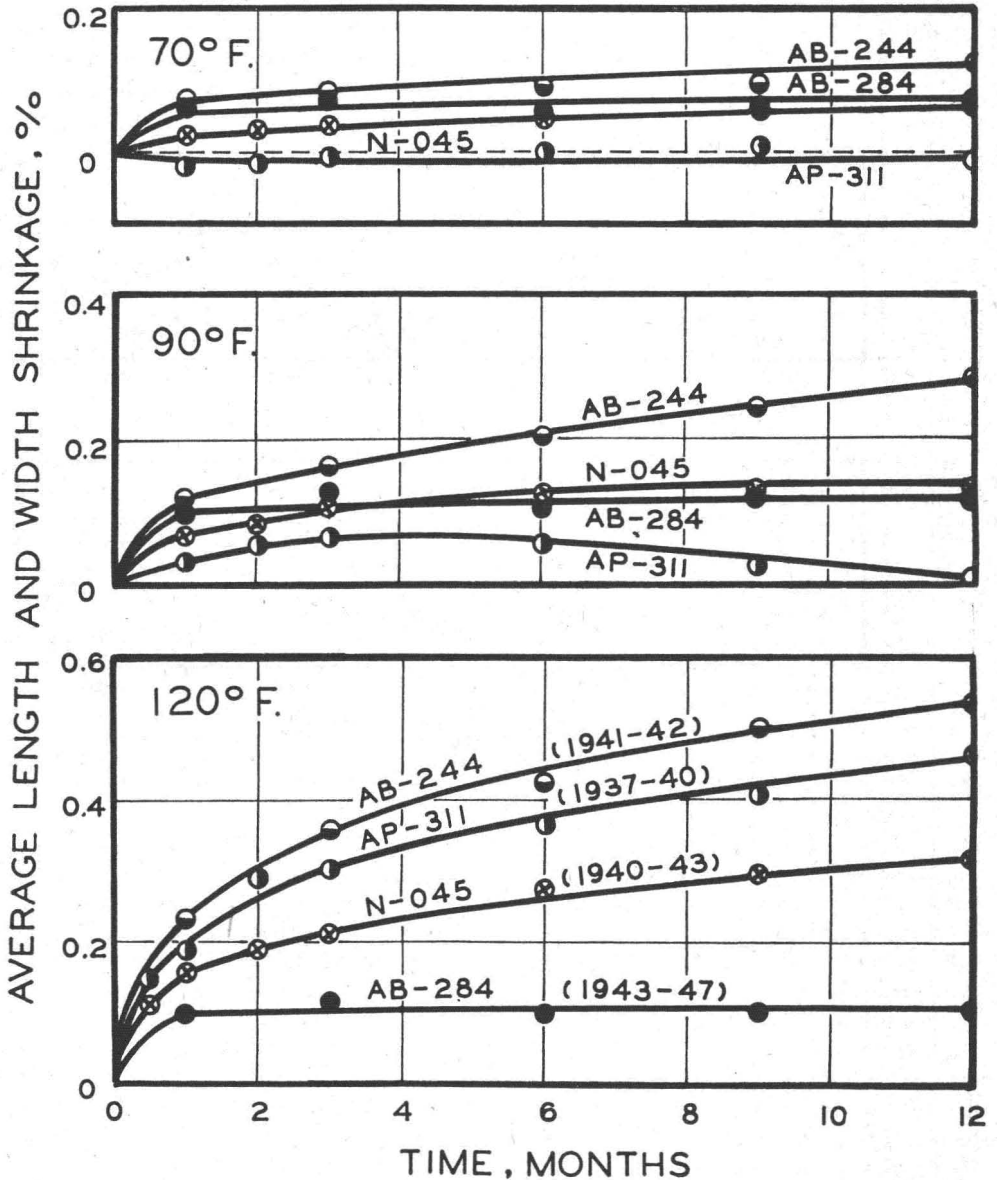


FIG. 23. The long-time average length and width shrinkage of Kodak Safety (AP-311, AB-244, AB-284) and Nitrate (N-045) Aero-graphic Films at various temperatures at 10-20% R.H. Film strips stored flat, open to air; reconditioned at 70°F., 50% R.H. for each measurement.

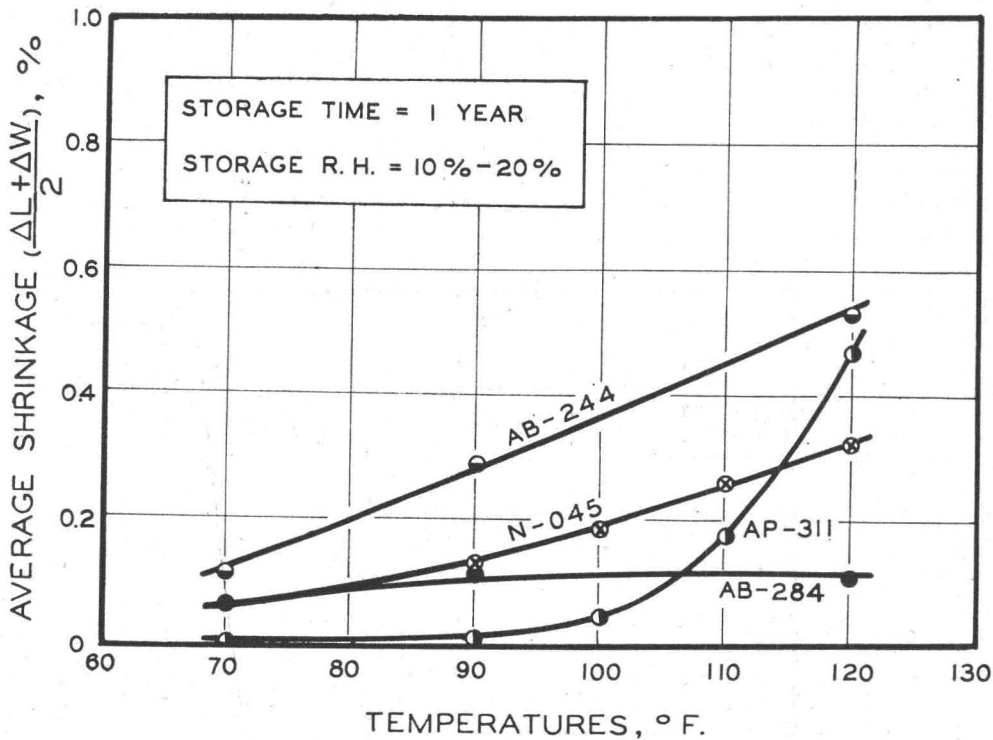


FIG. 24. The effect of temperature on the long-time average length and width shrinkage of various Kodak Safety (AP-311, AB-244, AB-284) and Nitrate (N-045) Aerographic Films. (Conditions same as for Fig. 23.)

supports have a lower modulus of elasticity and are compressed laterally by the emulsion at low relative humidities to a slightly greater extent than the nitrate. For the same reason the HA-411 film, which has a stiffer base than AB-284, for example, has about the same coefficient of humidity expansion in spite of a higher support swell in water.

The thermal expansion of the various films in Table V in general parallels the humidity expansion. Most of the Safety Aerographic films have a thermal expansion slightly higher than the nitrate, but lower than the regular acetate film. The safety HA-411, on the other hand, has virtually the same coefficient of thermal expansion as the nitrate. It was mentioned previously that the width minus length differential thermal expansion of various films correlates with the differential swell in water. This is confirmed by the comparison between Aerographic and Non-Topographic Aero films in Table V.

3. Permanent Shrinkage.—The long-time aging shrinkage of three Safety Aerographic Films (AP-311, AB-244 and AB-284) compared with Nitrate Aerographic Film (N-045) is shown in Figure 23 for three different storage temperatures. The shrinkage of the safety AP-311 is consistently lower than that of the nitrate at 70°F. and 90°F., but appreciably higher at 120°F. The latter is caused principally by the greater plastic flow of the AP-311 base at 120°F. under the compressive force of the emulsion (cf. Table II). Type AB-244 safety film has a higher long-time shrinkage than the other safety films or the nitrate at all three temperatures largely because of residual solvent in the base which is not indicated by short-time accelerated tests. This type of base used during the early part of the war was discontinued as soon as possible as previously explained.

The present Safety Aerographic Film (AB-284) is the equal of nitrate in long-time shrinkage at 70°F. and 90°F. and is superior to the nitrate as well as all earlier types of Safety Aerographic Film at 120°F (Figure 23). The apparent lower shrinkage of the older AP-311 film at 70°F. and 90°F. compared with AB-284 is believed to be due to differences in the conditioning technique employed in 1940 rather than to any real difference in dimensional stability. The effect of temperature on the long-time shrinkage of these films is illustrated more clearly in Figure 24. Long-time shrinkage tests on HA-411 have not yet been

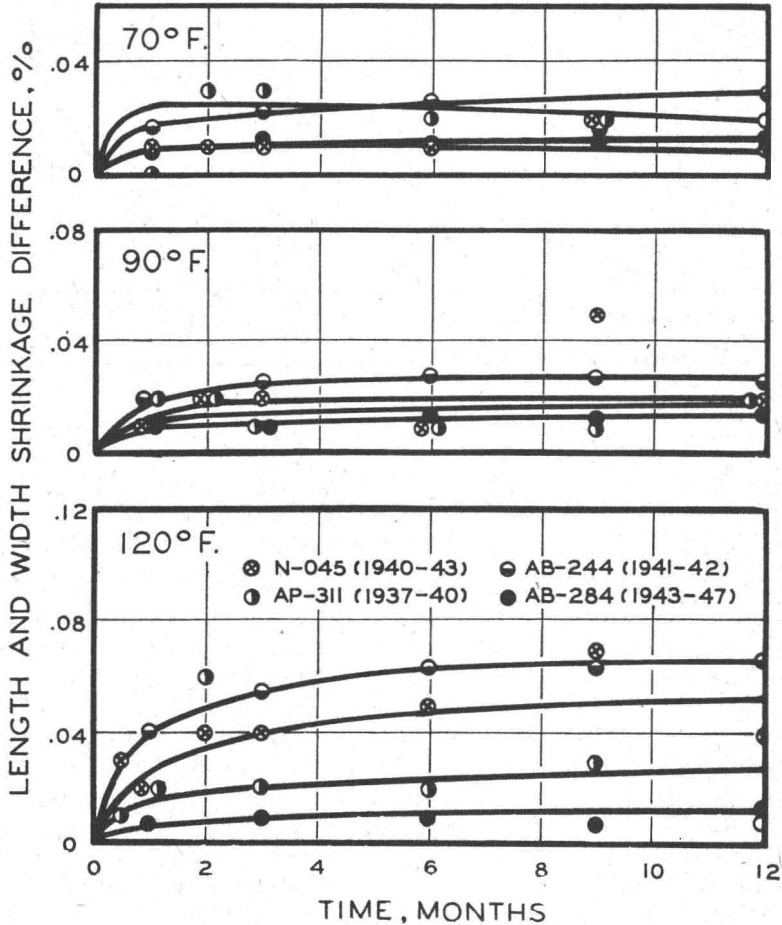


FIG. 25. The long-time length and width shrinkage difference of Kodak Safety (AP-311, AB-244, AB-284) and Nitrate (N-045) Aerographic Films. (Conditions same as for Fig. 23.)

completed but at the end of six months at 120°F., 20% R.H. the shrinkage averaged 0.22% compared with 0.11% for AB-284 under the same conditions. This is another reason why AB-284 is preferred to HA-411.

The length and width shrinkage difference or distortion of each of these Aerographic films on aging at the same three temperatures is shown in Figure 25. In general the differential shrinkage curves parallel the over-all shrinkage curves of Figure 23. The AB-244 is poorer than the nitrate at all temperatures but the present safety (AB-284) is as good as the nitrate at 70°F. and 90°F. and substantially better at 120°F.

The Accelerated Aging Shrinkage Test

Further discussion of the accelerated aging shrinkage test is warranted because it illustrates a number of shrinkage phenomena which account for some of the difficulties in maintaining constant film dimensions. The aging treatment of seven days at 120°F. was originally developed for testing relatively high shrinkage films for which it proved very satisfactory. However, it is much less satisfactory for very low shrinkage films such as Aerographic. Like all accelerated tests, it suffers from the fundamental weakness that the increased severity of the treatment may cause changes which do not occur in longer times under normal conditions. On the other hand, it is usually impractical to wait a long time for a natural aging test before accepting or rejecting a given film. Some of the variables which have been investigated are described below:

1. *The effect of sampling from film rolls.*—The first section of Table VI shows that film sampled from regular Aero spools or film held in small hand rolls prior to testing gives a higher length and width shrinkage difference after accelerated aging than the same film held flat between manufacture and testing. Furthermore, the smaller the diameter of the roll, the greater is the magnitude of the dis-

TABLE VI. THE EFFECT OF MISCELLANEOUS VARIABLES IN THE ACCELERATED AGING TEST ON THE APPARENT SHRINKAGE OF KODAK SAFETY AEROGRAPHIC FILM

	Accelerated Aging Shrinkage, %		
	Length	Width	Difference
1. The effect of sampling from film rolls. (Type AB-244 base).			
(a) Control stored flat between manufacture and testing.	.14	.16	.02
(b) Sampled from outside end of 75-ft. spool (4" dia.)	.13	.17	.04
(c) Sampled from core end of 75-ft. spool (2" dia.)	.12	.18	.06
(d) Sampled from hand roll wound emulsion-in widthwise for 7 days (1" dia.)	.16	.07	.09
2. Comparison of uncoated base and emulsion coated film (Type AB-284 base)			
(a) Aging 7 days at 120°F., 20% R.H.			
Uncoated base	.04	.04	.00
Emulsion coated film	.08	.08	.00
(b) Aging 7 days at 160°F.			
Uncoated base	.06	.06	.00
Emulsion coated film	.20	.19	.01
3. The effect of oven relative humidity at 120°F. (Type AB-244 base).			
(a) Oven at 6% R.H.	.15	.18	.03
(b) Oven at 20% R.H.	.09	.11	.02
(c) Oven at 50% R.H.	.05	.06	.01
4. The effect of thermal and moisture history of film prior to testing (Type AB-284 base).			
(a) Preconditioned 24 hours 70°F., 50% R.H. (Control)	.07	.06	.01
(b) Preconditioned 24 hours 85°F., 65% R.H.	.11	.11	.00
(c) Preconditioned 24 hours 90°F., 90% R.H.	.15	.15	.00

tortion. The direction of the effect also depends on whether the film is wound lengthwise or widthwise. Prior to 1942 fresh Aerographic film samples were rolled to about two inches in diameter widthwise for delivery to the testing laboratory. We now believe that the apparent greater length than width accelerated aging shrinkage of Aerographic films made before 1942 (Table V), which at the time was attributed to release of mechanical strain caused by the manufacturing process, was actually due to the handling of the film samples prior to testing. Since 1942 all film samples for control tests have been held flat between manufacture and testing to eliminate this variable which is discussed more fully in the next section.

2. *The effect of the emulsion.*—It was mentioned earlier that the emulsion introduces complicating factors in the accelerated aging test which have nothing to do with the manufacture of the film base. This is demonstrated in the second portion of Table VI which shows that AB-284 Aerographic base shrinks only about one-half as much as the finished film in a week at 120°F., 20% R.H., and one-third as much in a week at 160°F. This phenomenon is caused by plastic flow or creep of the base under the contractive force of the emulsion at the elevated temperature. Since this behavior is not related in any way to the curing of the film base, the accelerated aging test may be misleading as an index of long-time shrinkage for this type of film.

3. *The effect of the oven relative humidity.*—The third section of Table VI illustrates how the shrinkage of Aerographic film apparently increases as the relative humidity of the air in the aging oven decreases. This is in the opposite direction to what would occur if the shrinkage were caused by the loss of residual solvents, the release of mechanical strain in the base, or even plastic flow under the same force, because these effects are all accelerated by moisture. The explanation is again found in the contractive force of the emulsion which compresses the support laterally. Reducing the relative humidity in the oven evidently increases the contractive force of the emulsion to such an extent that it more than overcomes the increased stiffness of the base. The magnitude of the effect is large enough to be serious in control testing since the seasonal change in outside temperature and humidity in Rochester, N. Y., for example, causes variations from 3% R.H. to 22% R.H. when the air is heated to 120°F. When this was discovered in 1943, oven humidity controls were instituted and the Army-Navy specification now requires a relative humidity of 20% at 120°F. for this test. (See Appendix.)

4. *Effect of thermal and moisture history.*—Other difficulties have been encountered with accelerated aging shrinkage which have been traced to differences in the thermal and moisture history of the film prior to testing. The last section of Table VI shows that film exposed for a day to elevated temperatures and humidities exhibits higher accelerated aging shrinkage even though it is reconditioned at 70°F., 50% R.H., prior to the test. The swell which occurs at the high humidity is not completely eliminated by the conditioning procedure employed in the test, but is removed during the week's aging at 120°F., 20% R.H., causing an apparent increase in the average shrinkage. This hysteresis effect is increased by elevated temperatures. Aerial film conditioned at 70°F., 50% R.H., for example, and heated in an air tight can behaves just as if exposed to a very humid condition. From a practical point of view, this means that film exposed to heat or high humidity will return only very slowly to its standard dimensions at normal conditions.

Many other possible variables in the accelerated aging shrinkage test for aerial film, including processing and drying conditions, have been investigated but in spite of all refinements the reproducibility of the test is still considered

poor for manufacturing control. It will be clear from the above discussion why it is necessary to place the primary shrinkage control in the manufacture of Aero graphic film in tests made on the base before emulsion coating.

Film Distortion Caused by Storage in Roll Form

In the previous section it was observed that Aero graphic film sampled from standard Aero spools showed greater distortion in the accelerated aging test than the same film held flat previous to testing. This phenomenon has been investigated in some detail because the distortion caused by rolling film on Aero spools

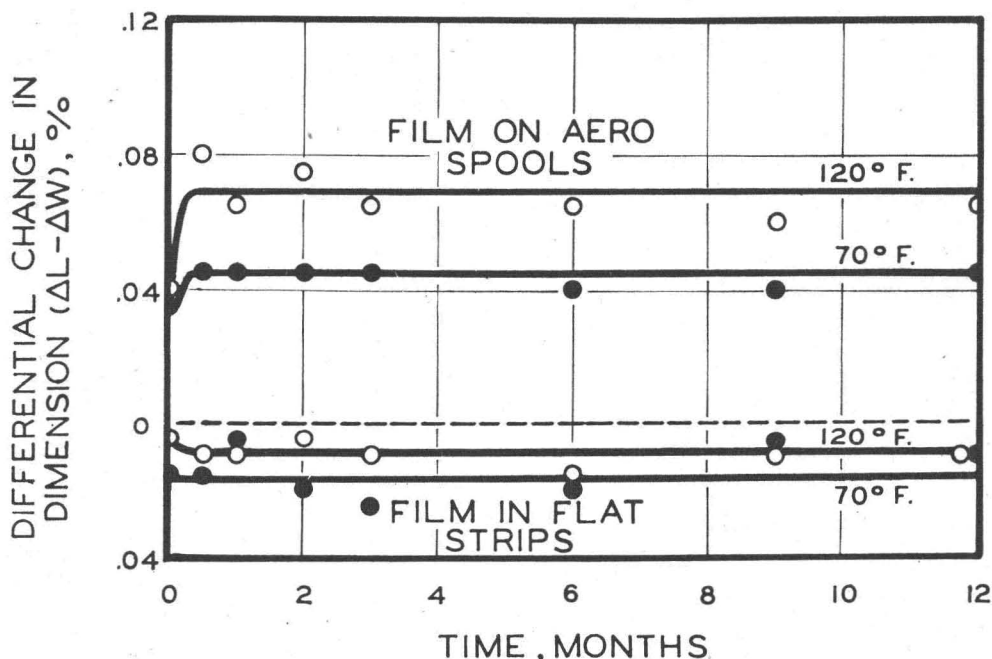


FIG. 26. The effect of distortion of storing Kodak Safety Aero graphic Film (Type AB-284 base) on regular Aero spools. Rolls $9\frac{1}{4} \times 10'$; spools 2" diameter core; film wound emulsion-in before exposure and emulsion-out after processing.

is sufficiently great that it may well explain why more distortion is sometimes encountered in practice than would be expected on the basis of control tests made on the fresh film.

A number of experiments have been conducted in an effort to determine the mechanism of the deformation which occurs when film is stored in roll form in the hope that this would lead to some method of prevention. Practical tests have been made comparing the dimensional change in film stored for long times on standard Aero spools with that of the same film stored flat. Figure 26 shows that the distortion is much greater in the film stored on Aero spools than in the same film stored flat and the effect increases with the storage temperature. Here, of course, the film is wound emulsion-in before exposure and emulsion-out after processing. The shrinkage of the spooled film in this test was measured by means of grid lines exposed on the emulsion, showing that the result is the same whether measurements are made by means of the photographic image or by means of perforations in the base as in the case of the strips in Table VI.

In another experiment, samples of both Safety and Nitrate Aero graphic

Film were obtained fresh and in flat form. After conditioning at 70°F., 50% R.H., a series of hand rolls were prepared one inch in diameter to exaggerate the effect. Some were wound lengthwise and others widthwise in respect to the coating direction; some were wound emulsion-in and others emulsion-out. These rolls were stored for seven days at 70°F., 50% R.H., then unwound and cut into 35-mm. strips. All strips were then tested for processing shrinkage, accelerated aging shrinkage and humidity amplitude. The original measurements, corresponding to the time of exposure, were made as soon as possible after unwinding (approximately fifteen minutes). The results are given in Table VII from which a number of interesting observations may be made by comparing the data for the samples previously rolled with those for the respective controls held flat.

TABLE VII. THE EFFECT OF PREVIOUS ROLLING ON THE DISTORTION OF KODAK AEROGRAFIC FILM

	Direction Rolled	Emulsion Side Wound In or Out	Change in Dimension, %								
			Processing			Accelerated Aging Test			Humidity Amplitude 20% to 70% R.H.		
			ΔL	ΔW	$\Delta L - \Delta W$	ΔL	ΔW	$\Delta L - \Delta W$	ΔL	ΔW	$\Delta L - \Delta W$
Safety Base, Type AB-284											
1. Flat (Control)			-.08	-.08	.00	-.11	-.10	-.01	.44	.46	-.02
2. Rolled	Lengthwise	In	.00	-.09	+.09	-.03	-.11	+.08	.50	.45	+.05
3. Rolled	Widthwise	In	-.09	.00	-.09	-.11	-.01	-.10	.43	.54	-.11
4. Rolled	Lengthwise	Out	-.16	-.07	-.09	-.16	-.09	-.07	.39	.47	-.08
5. Rolled	Widthwise	Out	-.13	-.16	+.03	-.14	-.17	+.03	.44	.41	+.03
Nitrate Base, Type N-045											
1. Flat (Control)			-.06	-.06	.00	-.14	-.15	+.01	.33	.36	-.03
2. Rolled	Lengthwise	In	+.03	-.06	+.09	-.05	-.14	+.09	.34	.34	.00
3. Rolled	Widthwise	In	-.06	+.03	-.09	-.14	-.05	-.09	.33	.37	-.04
4. Rolled	Lengthwise	Out	-.08	-.06	-.02	-.17	-.14	-.03	.30	.36	-.06
5. Rolled	Widthwise	Out	-.05	-.08	+.03	-.14	-.17	+.03	.33	.31	+.02

Film held in roll for 7 days at 70°F., 50% R.H. prior to testing. (Diameter of rolls, 1.0"). All measurements made at 70°F., 50% R.H. after first preconditioning at 70°F., 20% R.H. (Except for humidity amplitude). Accelerated aging, 7 days 120°F., 20% R.H. after processing.

Since the algebraic difference between the processing shrinkage and the accelerated aging shrinkage (which includes processing shrinkage) is approximately the same in all experiments in Table VII, the distortion caused by previous rolling is evidently released during processing and is in no way related to the treatment at 120°F. When the film is previously rolled emulsion-in, it expands during processing in the direction of rolling; when previously rolled emulsion-out, it contracts in the direction of rolling. However, no change in dimension occurs normal to the direction of rolling, relative to the flat control. The differential humidity amplitude of the film is also affected by the previous storage in roll form as indicated in Table VII. This can only mean that the deformation caused by rolling is released by conditioning at 70% R.H. (which follows the measurements at 20% R.H.) as well as by processing. This explains how the humidity expansion can sometimes appear to be greater in the lengthwise than in the widthwise direction even though any molecular orientation in the base makes the expansion greater in the widthwise than in the lengthwise direction. These facts, together with the observation made from Table VI that film distort-

tion caused by previous rolling increases as the radius of curvature decreases, lead to the conclusion that the phenomenon is caused by various elastic and plastic deformations. This being the case, safety base film, which has a lower modulus of elasticity and a higher plastic flow than nitrate, might be expected to show a different degree of distortion of this type. Table VII indicates the safety film to have only very slightly greater distortion than the nitrate film when previously rolled.

It was considered of interest to determine the effect of relative humidity on the rate of recovery of film deformation caused by previous rolling. Fresh samples of Aerographic film were obtained flat, conditioned at 70°F., 50% R.H., then rolled lengthwise to 1.0" diameter and held for seven days at the same condition. Strips were then cut in both length and width directions and the original

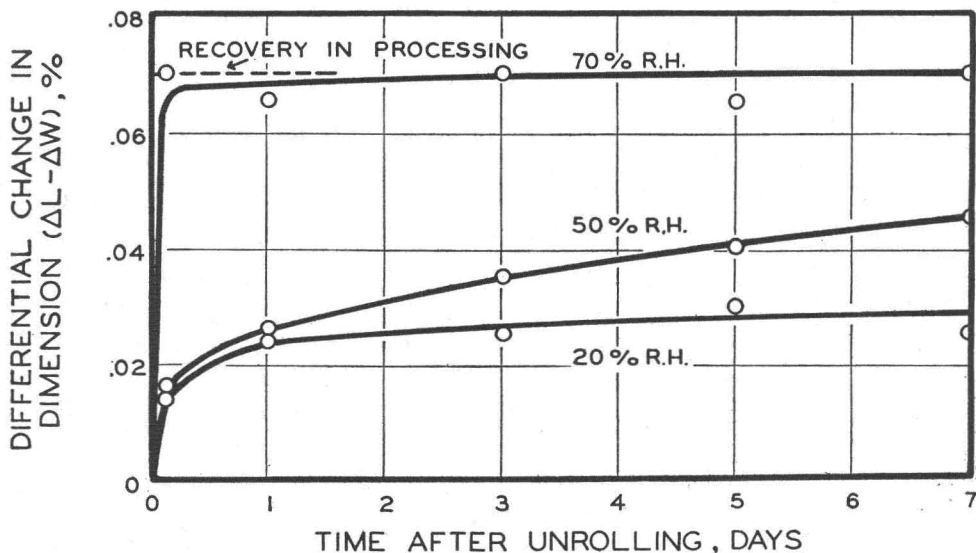


FIG. 27. The effect of relative humidity at 70°F. on the rate of recovery of distortion caused by previous rolling of raw Kodak Safety Aerographic Film (Type AB-284 base). Rolls 1.0" diameter, held 7 days at 70°F., 50% R.H. before unrolling and reconditioning at stated humidity.

measurements made fifteen minutes after unwinding. These strips were then conditioned and stored at 20%, 50%, and 70% R.H. at 70°F. along with flat controls. The change in distortion versus time at each humidity is plotted in Figure 27. It will be observed that the maximum distortion released during processing is also obtained in a few hours aging at 70% R.H. However, at 20% R.H. and 50% R.H. only one-third to one-half the distortion is released in seven days after unwinding. This means that the effect of previous rolling can be erased if the film is held flat for the proper length of time at a high relative humidity, but that recovery is relatively slow at 50% R.H. or lower. It also shows that moisture is instrumental in releasing the distortion caused by previous rolling, although temperature undoubtedly plays a part as well.

Since the effect of rolling on the subsequent dimensional behavior of the film is in the opposite direction when the film is wound emulsion-out than when it is wound emulsion-in (Table VII), it is evident that this type of distortion would not occur with the base alone because the latter is symmetrical. In other words, it is the two-layer structure of emulsion and support which is responsible in some way for the distortion caused by rolling. A further deduction is that the

magnitude of the distortion under a given set of conditions is related in some way to both the emulsion and base thickness.

To gain a clearer picture of this behavior, a series of films were coated experimentally using Aerographic base and a range of emulsion thicknesses from 0 to 1.1 mils. (Super XX Aerographic emulsion is approximately 0.8 mil thick and Aerographic base is about 5.3 mils thick). Lengthwise strips from these films, including uncoated base, were conditioned forty-eight hours at 70°F., 50% R.H., for the original measurement; some were then rolled emulsion-in and some emulsion-out to 1.0" diameter, and others held flat for controls. After seven days storage at 70°F., 50% R.H., in this form, each strip was unwound and remeasured immediately, corresponding to the condition at exposure. All strips were processed, preconditioned two hours at 70°F., 20% R.H., reconditioned twenty-four hours at 70°F., 50% R.H., and remeasured. Widthwise samples were not

TABLE VIII. THE EFFECT OF EMULSION THICKNESS ON FILM DISTORTION CAUSED BY STORAGE IN ROLL FORM PRIOR TO USE

Emulsion thickness, mils.	Change in Dimension, %			
	0	0.33	0.59	1.11
1. Film rolled emulsion-in before processing				
Change in dimension of raw film on unwinding.	+ .01	- .05	- .08	- .12
Change in dimension on processing.	.00	+ .04	+ .10	+ .14
Net change in dimension.	+ .01	- .01	+ .02	+ .02
2. Film rolled emulsion-out before processing				
Change in dimension of raw film on unwinding.	+ .01	.00	+ .04	+ .11
Change in dimension on processing.	- .01	- .01	- .04	- .12
Net change in dimension.	.00	- .01	.00	- .01

Kodak Safety Aerographic Film, (Type AB-284 base). Film wound in 1.0" diameter rolls (lengthwise only) and stored for seven days at 70°F., 50% R.H. before processing. All measurements made at 70°F., 50% R.H., average of four 35-mm. strips, corrected for change in dimension of controls held flat.

tested because previous experiments (Table VII) had shown that rolling causes no deformation normal to the direction of rolling. The distortion in the present case is thus equivalent to the deformation in the lengthwise direction corrected for any shrinkage of the flat controls.

The results of this experiment are given in Table VIII and confirm the deductions drawn. The magnitude of the distortion caused by previous rolling is zero for the uncoated base within experimental error, but increases in a marked fashion with increase in emulsion thickness. Furthermore, the deformation which becomes apparent in processing is approximately equal in magnitude but opposite in sign to the deformation found in the raw film immediately after unwinding. It is not practical to reduce the emulsion thickness appreciably because of photographic properties, but this experiment does help in understanding the cause of the deformation.

It is of interest to attempt to explain the dimensional phenomena which result from rolling film. When any sheet material is curved, the concave side is compressed and the convex side is stretched. The deformation of either surface

with respect to a parallel plane through the center of the sheet can be readily calculated from the radius of curvature and the sheet thickness as indicated in Figure 28. The magnitude of the surface deformation for a 0.006" sheet (the thickness of Aero-graphic film) is not inconsiderable, e.g., 0.6% for a 1.0" diameter roll, 0.3% for a 2.0" diameter roll, etc. Of course, this does not mean that the film as a whole will be deformed to this extent.

It was pointed out in connection with Figure 10 that a deformation in a plastic material is made up of elastic, delayed elastic, and plastic components. When photographic film is stored in roll form, plastic flow gradually takes place in both base and emulsion, resulting in a relaxation of the initial stress caused by winding. This is readily demonstrated by the fact that film released from a roll does not lie flat but tends to hold the shape it had in the roll even when natural curl is absent. For some reason, the plastic flow or set which occurs in the

roll must be greater in the emulsion side than in the base side, for when the film rolled emulsion-in is unwound, the base is evidently compressed in the direction of rolling more than the emulsion is stretched. This results in a net contraction of the film as shown in Table VIII, and illustrated in Figure 29, A. The compression of the base in unwinding must be largely of the delayed elastic type, which is recovered as soon as the film is humidified at 70% R.H., for example, or wet in processing solutions where the emulsion becomes relatively soft and weak. The film then expands to the original dimensions it had before rolling. The difficulty in practice is that the exposure is normally made a few seconds after the raw film is unrolled so that the portion of the deformation recovered in processing affects the dimensions of the image. In the case of the film rolled emulsion-out, the effect would naturally be in the opposite direction. When the roll is unwound, the base is evidently stretched more than the emulsion is compressed, resulting in a net expansion before exposure and a contraction in processing in the direction of rolling (Fig. 29, B).

The above explanation accounts qualitatively for many of the observed effects including the lack of distortion when uncoated base is stored in rolls. However, the mechanism of the deformation occurring in the roll and in unwinding is not entirely clear. It is evidently connected with differences between the base and emulsion in elastic modulus and plastic flow. Presumably, the emulsion is more susceptible to plastic flow than the base at 70°F., 50% R.H., but this relation will vary with the temperature and humidity, and the natural curl of the film adds additional complications.

One further experiment remains to be described which, perhaps, is of more practical interest. It is normal practice to wind raw aerial film emulsion-in and

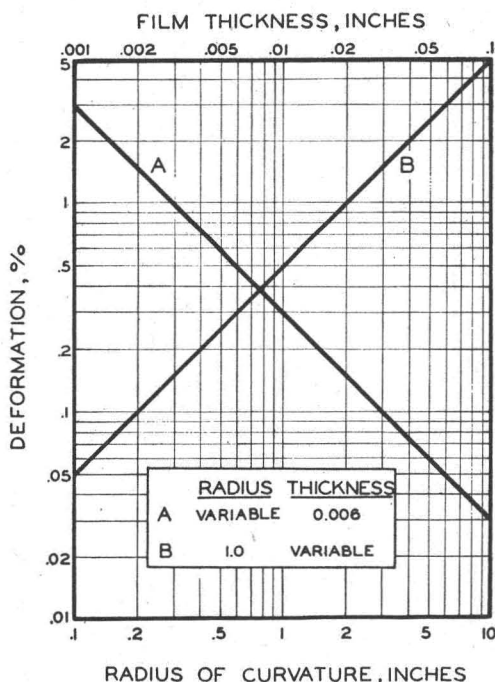


FIG. 28. Deformation of film surface when rolled (relative to plane through middle parallel to surface) for varying film thickness and radius of curvature.

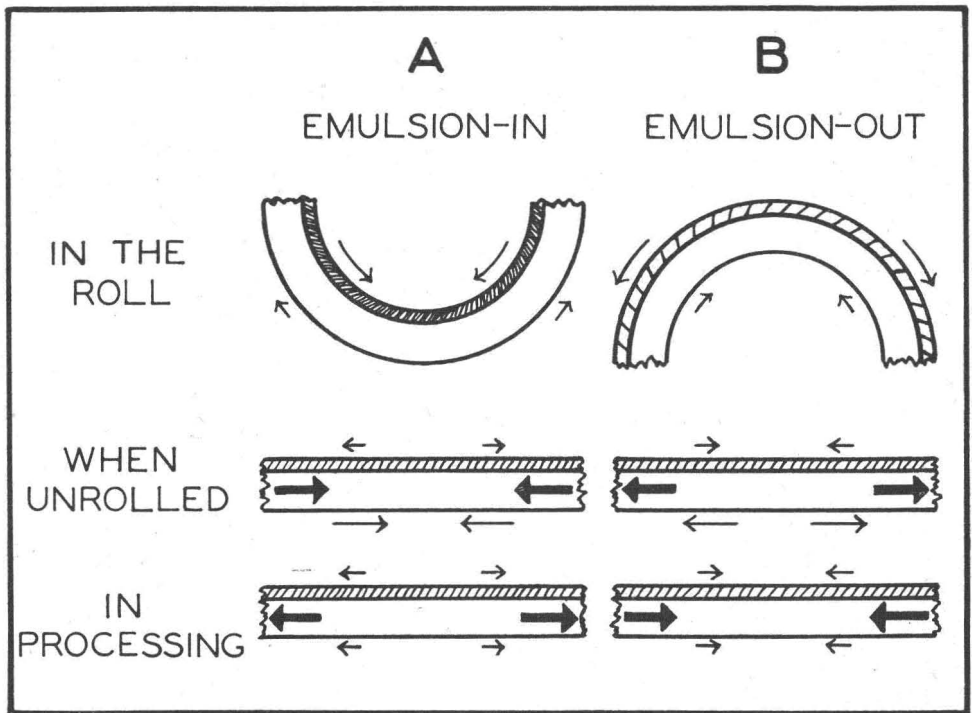


FIG. 29. Diagram illustrating the elastic and plastic deformations which probably occur when raw film stored in a roll is first unrolled and then processed. The heavy arrows indicate the direction of the over-all change in dimension.

developed film emulsion-out. In this test, developed film was also wound in the reverse direction (emulsion-in) to determine what effect this change would have on the distortion. Twenty grids were first exposed on each of two $9\frac{1}{2}$ " by 75-ft. rolls of Aero graphic film which had been wound on standard Aero spools emulsion-in for about three weeks. The exposure was made at 55% to 60% R.H.¹¹ at 70°F. as the film was unrolled. The film was respooled emulsion-in, processed and then one roll was wound emulsion-in, and the other emulsion-out. Ten flat sheets of film which had never been rolled were exposed to the same grids and tray developed for controls.

The data in Table IX and Figure 30 show that the distortion in the roll wound emulsion-in after processing is approximately the same as that of the control held flat. On the other hand, the roll wound emulsion-out in the normal manner has an appreciable distortion which increases gradually with the storage time. The magnitude of the distortion in the latter is less than in the laboratory experiments of Tables VII and VIII because of the larger diameter of the standard Aero spool core (2 inches). The distortion is also larger at the core end than at the outside end of the roll by about 0.02% of the dimension (data not shown). Winding the film emulsion-in after processing apparently tends to compensate for the original distortion. However, there is a disadvantage to this procedure because the reduction in curl obtained by winding the film inside-out is lost.

¹¹ This is the approximate relative humidity of the air with which the film is in equilibrium when it is sealed in the can.

TABLE IX. THE EFFECT ON DISTORTION OF WINDING FILM EMULSION-IN AFTER PROCESSING

Storage Time at 70°F., 50% R.H. after processing.	Change in Dimensions, %								
	Wound Emulsion-Out			Wound Emulsion-In			Stored Flat (Control)		
	ΔL	ΔW	$\Delta L - \Delta W$	ΔL	ΔW	$\Delta L - \Delta W$	ΔL	ΔW	$\Delta L - \Delta W$
1 day	-.042	-.073	+.031	-.058	-.071	+.013	-.051	-.058	+.007
2 weeks	-.048	-.084	+.036	-.088	-.091	+.003	-.057	-.062	+.005
1 month	-.048	-.089	+.041	-.103	-.099	-.004	-.066	-.071	+.005
2 months	-.058	-.101	+.043	-.109	-.109	.000	-.084	-.083	-.001
3 months	-.057	-.105	+.048	-.111	-.117	+.006	-.081	-.079	-.002
4 months	-.067	-.111	+.044	-.117	-.124	+.007	-.069	-.070	+.001

Kodak Safety Aerographic Film, (Type AB-284 base). Film rolls 9½" X 75' on standard Aero spools 2" diameter core; control 9½" X 9½" sheets. Both rolls wound emulsion-in for three weeks before testing; control held flat from time of manufacture. All measurements made at 70°F., 50% R.H. without other conditioning; average of ten to twenty grids.

To what extent the distortion caused by rolling film is important under actual service conditions is not known. It may account for some of the differential dimensional changes observed by Carman (5) which could not be explained by other known variables. A great deal of work remains to be done before the effect of rolling film can be fully understood and before the magnitude of this type of distortion under service conditions can be accurately determined and steps taken to minimize it.

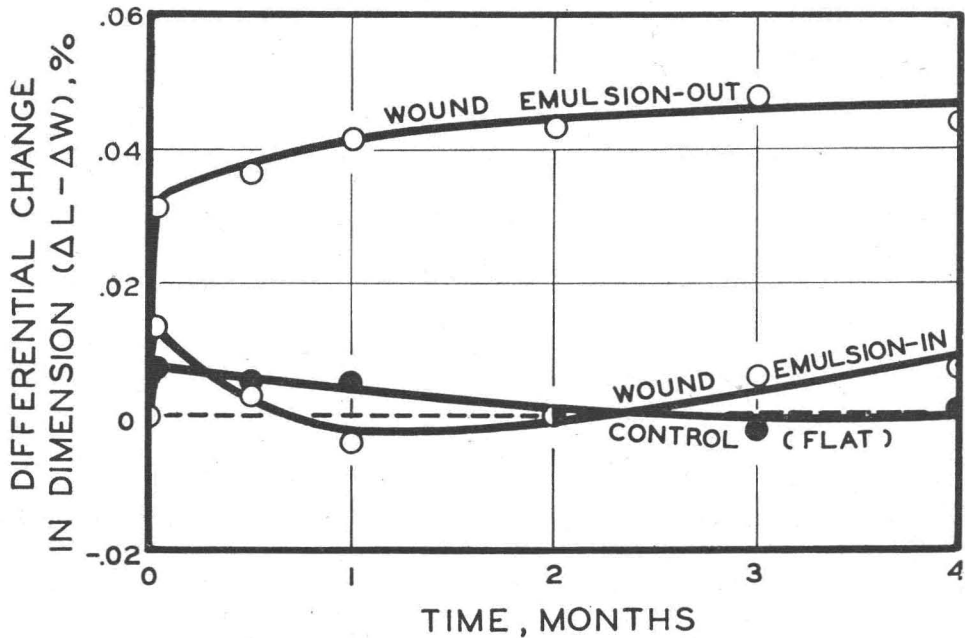


FIG. 30. The effect on distortion of winding Kodak Safety Aerographic Film (Type AB-284 base) emulsion-in after processing. Rolls 9½" X 75'; spools 2" diameter core; storage conditions 70°F., 50% R.H.

VI. PRACTICAL ASPECTS OF FILM HANDLING RELATED TO DIMENSION STABILITY

In Section V the fundamental dimensional behavior of Safety Aerographic Film under various laboratory conditions of temperature and humidity has been described. In this section a discussion is given of some of the more practical problems involved in handling aerial film which affect its dimensional stability.

Dimensional Changes Occurring Inside the Camera

The preparation of accurate topographic maps from aerial photographs requires that any distortion in the film between the instant of exposure and the instant of printing be as low as possible. In cameras at high altitudes the temperature of the film may be reduced prior to exposure and when the film is re-

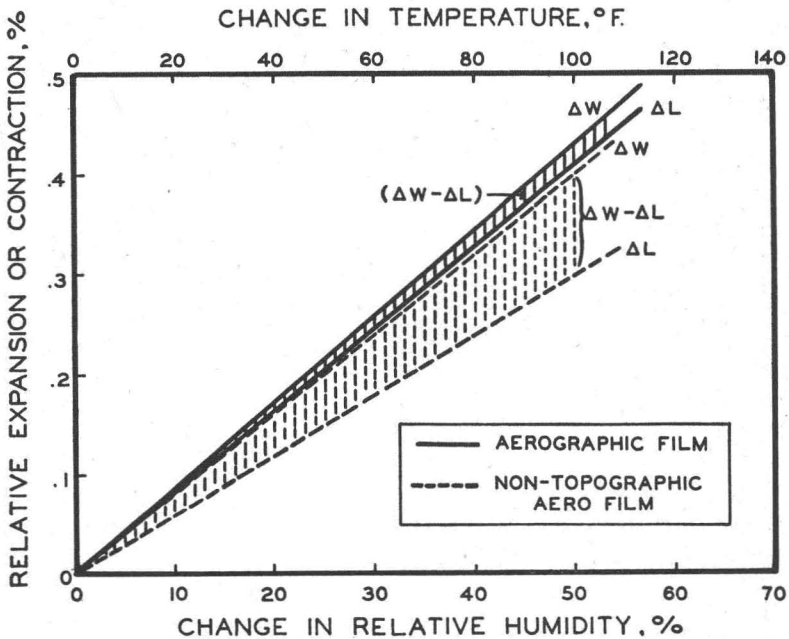


FIG. 31. Diagram illustrating relation between distortion ($\Delta W - \Delta L$) and over-all humidity or thermal expansion and contraction for Kodak Safety Aerographic and Non-Topographic Aero Films.

turned to the ground for processing and printing, thermal expansion occurs (5). Moisture changes may also take place in the film before exposure depending on the relative humidity of the air inside the camera. (Aerographic film is in equilibrium with air at 55% to 60% R.H. when sealed in the can.)

If topographic aerial film were perfectly uniaxial, thermal and humidity expansion would not cause distortion. However, this ideal has never quite been achieved and it is only by holding the over-all dimensions of the film as constant as possible that distortion of this type can be prevented. This is illustrated in Figure 31 which shows how distortion increases with increase in the over-all dimensional change resulting from change in temperature or humidity. Although the magnitude of the distortion is very much less in Aerographic than in Non-Topographic Aero film, it can be reduced to a still lower level by maintaining the film at the same temperature and humidity during exposure that prevails at the time of printing.

Data on the rate of thermal conditioning of aerial film between 70°F. and -10°F. determined by means of thermocouples are given in Figure 32. These conditions roughly approximate what may happen when an unheated camera loaded with film at room temperature is flown to a high altitude. One or two layers of film freely exposed to circulating air require only a minute or two to reach thermal equilibrium. A single layer of film placed in the focal plane inside an aerial camera at room temperature requires several hours to reach thermal equilibrium because of the mass of metal in the camera to be cooled. The interior of the 200-ft. $\times 9\frac{1}{2}$ " feed roll does not reach thermal equilibrium in less than ten hours. Thus the actual temperature of the film at the instant of exposure may vary greatly even between successive frames, depending on the time interval

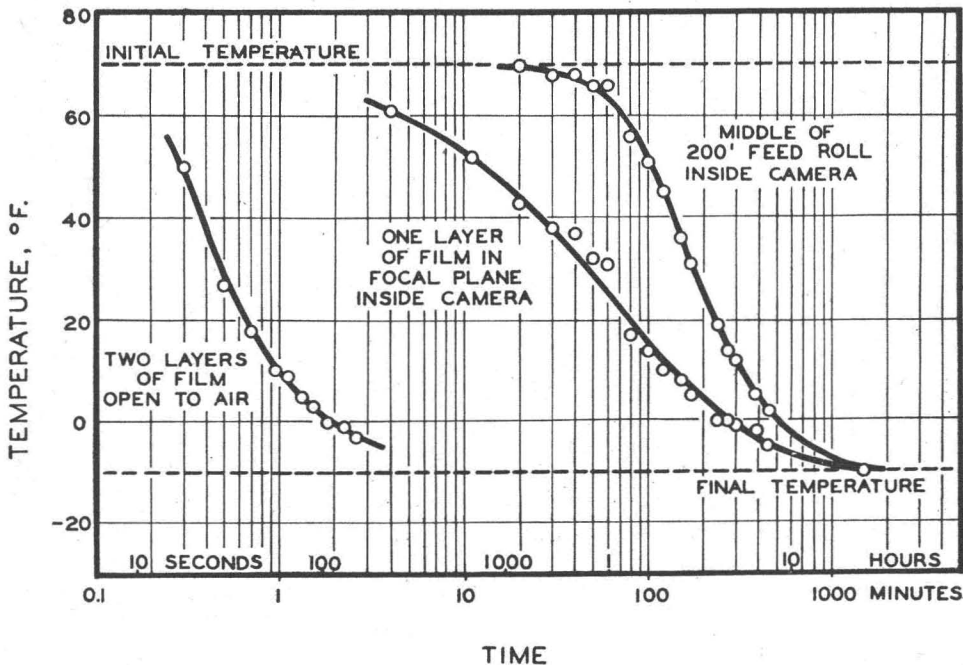


FIG. 32. The rate of thermal conditioning of film. Fairchild K-17B Aerial Camera; Kodak Safety Aerographic Film. (No suction on magazine).

between exposures, the ground temperature, the air temperature, ventilation and other factors.

The rate of moisture conditioning of a single layer of film from one relative humidity to another has been given in Figures 5 and 6. Film on Aero spools conditions much more slowly. An experiment showed that a $9\frac{1}{2}$ " roll of Aero graphic film initially in equilibrium with air at 50% R.H., when placed in an atmosphere at 20% R.H. at 70°F., was in equilibrium with air at the following humidities after eight hours:

- 1st lap 33% R.H.
- 2nd lap 46% R.H.
- 3rd lap 49% R.H.

In other words, moisture exchange through the laps of a large roll of film is extremely slow. The most likely chance for moisture changes inside the camera is between flight lines when the film may remain stationary in the focal plane for twenty minutes or longer. It is well known that the first few exposures made

at the start of a flight line show greater dimensional changes than the average (5).

The only really effective way to prevent these thermal and moisture changes in the film between exposure and printing is to air condition both camera and laboratory at the same temperature and relative humidity as the air with which the film is in equilibrium when packed by the manufacturer. Even if the camera air cannot be conditioned to the proper humidity, thermostating at the laboratory temperature would be a great improvement. Dimensional errors caused by moisture changes in the film can then be minimized by discarding several exposures before starting each flight line as recommended by Carman (5).

The Effect of Tension in Processing

It has long been recognized that aerial film for topographic mapping must not be stretched in processing or drying if excessive distortion is to be avoided. Not only must the film not be elongated, it must be allowed to contract freely in drying. If such contraction is prevented, the net result is the same as actual stretching.

The question is frequently raised as to just how much tension can be permitted, particularly in continuous processing machines. The approximate tensions required to produce a given elastic or plastic deformation in Safety Aero-graphic Film under several conditions of temperature and humidity as well as when soaked in water have been determined (Table X). The elastic deformation was calculated directly from the modulus of elasticity. Plastic flow was determined by applying a dead load to 15-mm. strips of film for ten minutes (a time of the same order of magnitude as the developing or drying time) and allowing twenty-four hours recovery before measuring the permanent deformation. Curves of load versus plastic flow were then plotted from which the load for a given flow could be determined by interpolation or extrapolation. A deformation of 0.05% was selected for comparison. Since lengthwise stretch is generally accompanied by loss of width, the corresponding distortion would be larger.

Table X shows that a momentary tension of seven to fifteen pounds on a 9½" width of film would produce an elastic deformation of 0.05% under the various conditions selected. This is not detrimental since it is recoverable. To produce a permanent stretch of 0.05%, a tension of 100 to 300 pounds acting for ten minutes would be required. The same deformation would be produced by lower tensions acting for longer times or at higher temperatures. A tension of 25 pounds on a 9½" width of film during processing might produce a measureable

TABLE X. THE EFFECT OF HEAT AND MOISTURE ON THE TENSION REQUIRED TO PRODUCE A GIVEN FILM DEFORMATION

Equilibrium Condition	Modulus of Elasticity, 10 ⁵ psi.	Tension Required to Produce 0.05% Elastic Deformation (Recoverable)		Tension Required to Produce 0.05% Plastic Flow (Non-Recoverable)*	
		psi.	Lbs./9.5" Width	psi.	Lbs./9.5" Width
70°F., 50% R.H.	4.6	230	14	5,600	330
70°F., water	2.5	125	7.5	1,900	110
90°F., 20% R.H.	4.3	215	13	4,200	250
120°F., 20% R.H.	4.1	205	12	3,200	190

Kodak Safety Aero-graphic Film (Type AB-284 base).

* Time loaded, 10 minutes; recovery time, 24 hours at 70°F., 50% R.H. for plastic flow test.

TABLE XI. THE EFFECT OF VARIOUS PRACTICAL PROCESSING AND DRYING CONDITIONS ON THE FILM PROCESSING SHRINKAGE

Processing Conditions	Drying Conditions	Change in Dimension, %		
		ΔL	ΔW	$\Delta L - \Delta W$
1. Tray, 65-70°F.	Suspended from racks at 70°F., 50% R.H.	-.041	-.070	+.029
2. Fairchild-Smith portable roll film developing outfit, 70°F.	Modified Smith portable roll film drier, 70°-80°F.	-.019	-.033	+.012
3. Fairchild-Smith portable roll film developing outfit, 70°F.	Modified Smith portable roll film drier, 130°-140°F.	+.033	+.036	-.003
4. Fairchild-Smith portable roll film developing outfit. Tropical developer, 95°F.	Modified Smith portable roll film drier, 130°-140°F.	+.030	+.027	+.003
5. An Army N-2 trailer continuous processing machine, 68°F.	Heated drum type of drier, 130°-140°F.	+.184	+.021	+.163
6. Kodak continuous processing machine, 68°F.	Drier similar to Smith portable roll film drier, 90°F., 30% R.H.	+.015	-.015	+.030

Kodak Safety Aerographic Film, (Type AB-284 base.) Standard $9\frac{1}{2}$ " rolls on Aero spools, average of ten grids per roll. Film conditioned at 70°F., 50% R.H. before and after processing, except (6) conditioned at 70°F., 60% R.H.

degree of distortion but this is a much higher tension than is necessary even in a continuous machine.

The effect of various processing and drying methods used in practice on the processing shrinkage of Aerographic film is given in Table XI. Regular $9\frac{1}{2}$ " rolls on Aero spools were employed for these tests, the film being conditioned on racks at 70°F., 50% R.H., before being exposed to the standard grid lines. After processing, the film was reconditioned to the same relative humidity before measurement. The data show no evidence whatever of film stretching as a result of processing in the Fairchild-Smith portable roll film developing outfit (even at 95°F.), or of drying in a modified Smith portable roll film drier.¹² Neither of these pieces of equipment put a significant tension on the film.

The processing shrinkage obtained with two different types of continuous processing machine is also shown in Table XI. The Army N-2 trailer continuous machine (5, Table XI) was designed during the war for the rapid processing of reconnaissance film. Drying is accomplished by means of a heated, revolving drum. The film is wrapped tightly around the drum, the base side next to the metal. This type of drying does result in appreciable stretching with consequent distortion, as indicated by the differential processing shrinkage obtained. Driers of this type should not be used for topographic aerial film intended for accurate mapping work.

The second continuous processing machine studied (6, Table XI) was designed and built by the Eastman Kodak Company for the processing of aerial test films. It is like the trailer unit described above except that the drier is similar to the Smith portable roll film drier rather than the hot drum type of drier. The tension on the film in the wet end of this machine was measured and

¹² The Smith portable roll film drier employed in these tests was modified to increase the air velocity; no change affecting film tension was made.

TABLE XII. THE EFFECT OF ALCOHOL DRYING ON THE SHRINKAGE OF KODAK AEROGRAPHIC FILM

Type of Base				N-053* Nitrate		AB-284 Acetate Butyrate		HA-411 High Acetyl Acetate	
Alcohol Type	Alcohol Conc., % By Volume	Temp., °F.	R.H. %	Processing Shrinkage, %	Accelerated Aging Shrinkage, %	Processing Shrinkage, %	Accelerated Aging Shrinkage, %	Processing Shrinkage, %	Accelerated Aging Shrinkage, %
Effect of Alcohol Type and Concentration									
None (control)	—	78	low	.02	.10	.03	.11	.03	.13
Methyl	50	78	low	.04	.13	.13	.21	.14	.23
	60	78	low	.07	.16	.22	.29	.21	.32
	70	77	30	.10	.16	.37	.41	.42	.47
	80	77	30	.20	.28	.69	.73	.62	.70
Ethyl	50	76	16	.03	.13	.07	.22	.09	.24
	60	76	16	.05	.15	.11	.26	.12	.29
	70	75	24	.10	.17	.37	.44	.32	.44
	80	75	24	.13	.20	.49	.54	.35	.46
Isopropyl	50	78	20	.02	.07	.04	.11	.07	.12
	60	76	low	.01	.07	.03	.14	.04	.11
	70	76	low	.01	.06	.03	.15	.01	.05
	80	78	20	.04	.07	.02	.17	.07	.09
Effect of Temperature									
None (control)	—	90	90	.00	.11	.02	.11	.03	.15
Methyl	50	90	90	.08	.20	.28	.40	.35	.48
Ethyl	50	90	90	.06	.17	.30	.41	.34	.49
Isopropyl	50	90	90	.01	.11	.22	.34	.19	.32
None (control)	—	105	78	.01	.13	.00	.12	.02	.16
Methyl	50	105	78	.12	.26	.46	.63	.54	.71
Ethyl	50	105	78	.09	.22	.59	.72	.64	.80
Isopropyl	50	100	78	.00	.13	.30	.47	.27	.43

* N-053, low shrinkage nitrate film similar to N-045 Aerographic (cf. Table V), except that it is not uniaxial.

Film processed by tray, rinsed $2\frac{1}{2}$ minutes in alcohol solution and dried in air. Processing temperature about 75°F. in all experiments; alcohol rinse temperature same as air temperature. Accelerated aging shrinkage is processing shrinkage plus aging shrinkage seven days 120°F., 20% R.H.

found to be approximately 5 lb. at the first developing tank and 10 lb. at the wash tank with the film running at a speed of 5 ft. per minute. The tension in the drier is virtually zero. Comparing these figures with the data on tensions in Table X, it is evident that there is a considerable margin of safety. This is confirmed by the actual shrinkage tests on film processed in this machine (6, Table XI).

It should be noted that the positive level of the average length and width processing shrinkage for experiments 3, 4, and 5 (Table XI) is caused by hysteresis as a result of the 130°–140°F. drying temperature. Experiment 6, dried at 90°F. shows the same effect to a lesser degree.

Alcohol Drying

It has been the practice in England for many years to accelerate the drying of aerial film by means of an approximately $2\frac{1}{2}$ minute rinse in a 50% to 70% methyl alcohol solution after washing. This is apparently satisfactory with nitrate base film, but is not satisfactory with safety film because the shrinkage of the latter is increased by the alcohol treatment. Under some conditions, the safety film may also be warped or made more curly by immersion in alcohol solutions. This difficulty has delayed the acceptance of safety base aerial film in England for a number of years. It was thought desirable to present some data comparing the shrinkage of Safety and Nitrate Aerographic Films rinsed in alcohol solutions under various conditions; particularly since there is also interest in this type of drying for very humid climates such as exist in the tropics.

The processing and accelerated aging shrinkage of Safety Aerographic Film subjected to a $2\frac{1}{2}$ minute rinse in various alcohol solutions after washing is given in Table XII. No Nitrate Aerographic Film was available for comparison so that it was necessary to use N-053, which is a low shrink nitrate film similar to

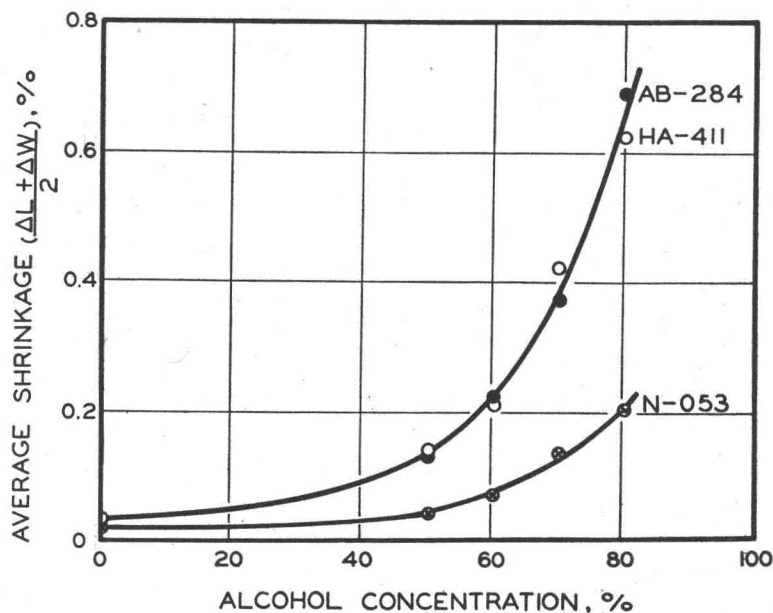


FIG. 33. The effect of methyl alcohol rinse concentration on the processing shrinkage of Kodak Safety Aerographic Film (AB-284, HA-411) compared with low shrink nitrate film (N-053). Rinse time, $2\frac{1}{2}$ minutes; temperature 77°–78°F.; relative humidity low.

N-045 (cf. Table V) except that it is not uniaxial. For this reason, individual length and width measurements are not shown in Table XII, but it is safe to assume that the distortion would be roughly proportional to the over-all shrinkage. Two types of Safety Aerographic Film are included in the comparison—the present acetate butyrate (AB-284), and also the high acetyl acetate (HA-411). It was hoped that the latter would be more resistant to the alcohol treatment than previous types of safety film, but this did not prove to be the case.

The effect of methyl alcohol rinse concentration on the processing shrinkage of the three types of film is illustrated in Figure 33. Both safety films show approximately the same shrinkage which is considerably higher than the nitrate

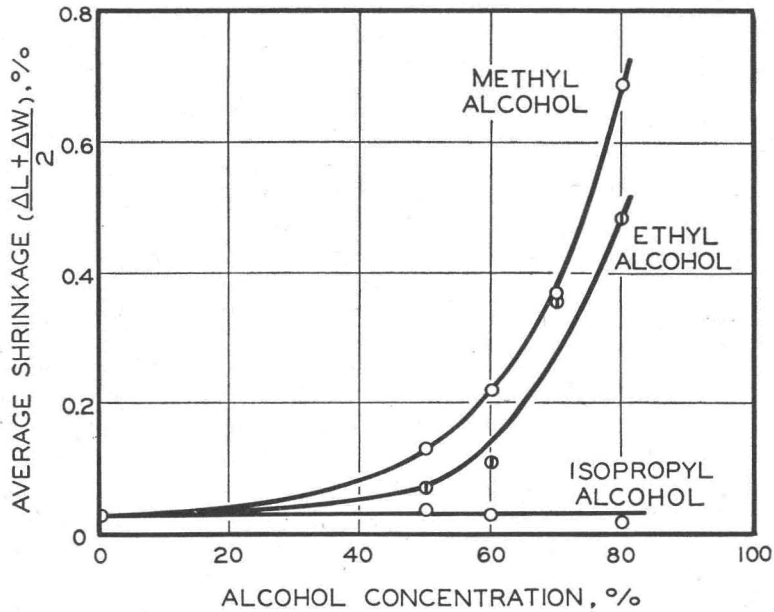


FIG. 34. The effect of alcohol type rinse concentration on the processing shrinkage of Kodak Safety Aerographic Film, (Type AB-284 base). Rinse time, $2\frac{1}{2}$ minutes, temperature 75° – 78° F.; relative humidity 15–30%.

and increases with the alcohol rinse concentration. Above 70% methyl alcohol, the nitrate film also shows an undesirable increase in shrinkage.

In Figure 34 a comparison is given of the effect of methyl, ethyl, and isopropyl alcohol rinses on the processing shrinkage of AB-284. Tests were made with the higher alcohols in the hope that these would cause less shrinkage. Some improvement was obtained, particularly with isopropyl alcohol, although even here the accelerated aging shrinkage (Table XII) increased as compared with the control. The effect on shrinkage of increasing alcohol temperature accompanied by drying under tropical conditions of temperature and humidity is also given in Table XII and illustrated (in the case of AB-284) in Figure 35. The shrinkage of all three films when rinsed in any of the three alcohols increases with increase in temperature. Even isopropyl alcohol at a concentration of 50% causes excessive shrinkage under these conditions.

Here another phenomenon must be mentioned. It was found that the isopropyl alcohol rinse causes a silvery white opalescent appearance in the emulsion which is quite objectionable. This effect has been observed frequently when film is rinsed in ethyl alcohol solutions under certain conditions and is appar-

ently due to a partial "precipitation" or reorganization or possibly dehydration of the gelatin particles. It disappears when the film is wet again in water and redried. In the case of ethyl alcohol the opalescence is produced only if high alcohol concentrations or drying temperatures above 70°F. are employed, whereas no opalescence occurs with a pure methyl alcohol rinse and a drying temperature of 120°F. (19, 20). Isopropyl alcohol, on the other hand, produces severe opalescence in a concentration of 50% even when the film is dried at room temperature. The tendency to produce opalescence in the emulsion evidently increases with the molecular weight of the alcohol.

It may be concluded from these data that safety base aerial film should not

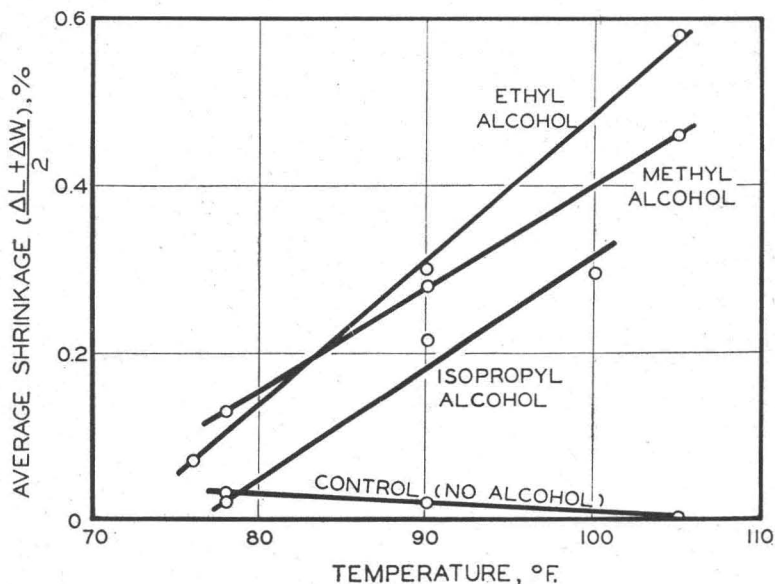


FIG. 35. The effect of temperature on the processing shrinkage of Kodak Safety Aerographic Film (Type AB-284 base) rinsed in various alcohol solutions. Alcohol concentration, 50%; rinse time $2\frac{1}{2}$ minutes; relative humidity, variable (cf. Table XII).

be rinsed in either methyl, ethyl, or isopropyl alcohol where a high degree of accuracy in topographic mapping is desired. Isopropyl alcohol cannot be used in any case because of the objectionable silvery white opalescent appearance it gives the emulsion. Rinsing film in alcohol solutions at elevated temperatures and drying under conditions such as exist in tropical climates is particularly detrimental to dimensional stability and may be permitted only in the case of reconnaissance film where saving a few minutes is more important than low shrinkage. Even nitrate film should not be rinsed in alcohol solutions under these conditions if intended for accurate mapping work.

It is recommended that where topographic aerial film is being processed under humid conditions, auxiliary heat be supplied to the air. This can readily be done by placing electric or gasoline heaters in the air intake of the drier. Temperatures up to 140°F. can be used safely and high drying rates obtained without stretching the film, provided that the tension is not excessive.

Printing and Storage of Aerial Negatives

To reduce dimensional errors in prints made from aerial film negatives, it is very desirable that printing be done in an air conditioned laboratory at con-

stant temperature and relative humidity. Ideally the negative should be in equilibrium with air at the same temperature and humidity at the time of printing as existed at the instant of exposure. This would also require air conditioning, or at least thermostating of cameras as already mentioned. In so far as dimensional stability is concerned, the relative humidity selected for the printing laboratory should be the same as that of the air with which the film is in equilibrium when packed by the manufacturer (55% to 60% R.H., in the case of Aerographic film). However, lower relative humidities (40% to 50% R.H.) are generally recommended for the long-term preservation of photographic records and it would not be practical to have two different conditions for printing and storage. A relative humidity of 50% R.H. is therefore a good compromise. The laboratory temperature is limited by working comfort to about 70°F. to 75°F.

In addition to the advantages gained in reduced dimensional errors, air conditioning of laboratories is most desirable from the point of view of the physical properties of the film. As we have seen, low relative humidities, such as occur in heated buildings in cool weather as well as in many natural climates, increase the curl and brittleness of film and the chance of tears or breaks. Excessively high humidities (above 70% R.H.) are likewise undesirable because the film is rendered somewhat limp and soft, and the emulsion may become tacky and may be damaged by mold. Air conditioning at 50% R.H. eliminates or minimizes all of these dangers and difficulties and this practise cannot be recommended too highly.

Illumination in printers should be arranged in such a way as to prevent negatives from becoming heated. It is assumed here that glass plate diapositives are made and not paper prints, since even special aerial mapping papers have considerably more shrinkage and distortion than Aerographic film. If dimensional data are to be taken from paper prints, there is little point in being concerned about the small dimensional changes which occur in the negative.

In so far as dimensional stability is concerned, it is most important to avoid elevated temperatures and extremes of relative humidity in the storage of safety aerial film negatives. It is desirable to have an air conditioned vault controlled at the same temperature and relative humidity as the printing laboratory, i.e., approximately 70°F., 50% R.H. This is particularly true in the case of valuable negatives which are to be preserved for many years. The film should be stored on regular Aero spools inside individual cans such as those in which the raw film is purchased. Film exposed in a camera thermostated at room temperature and printed in an air conditioned laboratory should be wound emulsion-in for storage to minimize distortion caused by rolling (cf. Section V and Figure 30). If thermal and humidity expansion are not eliminated between exposure and printing, it is probably better to wind the processed film emulsion-out since these two types of distortion are opposite in direction. If low relative humidities cannot be avoided in the laboratory, winding the film emulsion-out also has the advantage of reducing curl.

If an air conditioned space is not available for storage, the rolls of aerial negatives may be sealed in cans by means of a good quality adhesive tape after first conditioning, preferably at 50% R.H. and in any case not below 25% or above 60% R.H. Refrigeration is seldom necessary in the storage of safety films although some cooling is desirable in very warm climates. It should be noted that wherever the storage space is at a temperature below the dew point of the outside air the film container should be allowed to warm up before it is opened in order to prevent condensation of moisture on the film.

Aside from the question of dimensional stability, there are a number of other factors which must be considered in the storage and preservation of aerial nega-

tives. The precautions and protection required for the preservation of safety base aerial films are essentially the same as for other valuable photographic records such as microfilms and a detailed discussion of this subject is given elsewhere (21). Briefly, the processed negatives should be thoroughly washed to remove soluble silver compounds and hypo which are likely to cause staining, and they must be protected against fire, water, mold and chemical or physical damage. Nitrate aerial film (used in the United States up until 1942) represents a special storage hazard. It should be kept only in fire-resistant vented vaults and should never be stored with safety film.¹³

VII. CHEMICAL STABILITY

Although the subject of this paper is primarily the physical properties of Safety Aeronographic Film, it is incomplete without brief mention of the relative chemical stability of safety and nitrate film base. Nitrate base, which, after all, is chemically similar to gun cotton, is fundamentally unstable. It decomposes slowly with time even at room temperature and gives off minute quantities of nitrogen oxides which accelerate further decomposition. This chemical deterioration of nitrate base results in a yellow discoloration and also gradual embrittlement as well as loss of strength and flexibility. Under less favorable conditions nitrate film may decompose with violence. It can be handled, shipped, and stored safely only by taking the most elaborate precautions and at considerable expense. The advantages of safety base over nitrate for aerial film from the point of view of chemical stability are discussed under storage of the unexposed film, preservation of valuable negatives, and reduced fire hazard.

Storage of the Unexposed Film

Some of the nitrogen oxides produced by the spontaneous decomposition of nitrate film base are poisonous to fast photographic emulsions. This means that emulsions coated on safety base have better keeping qualities than when coated on nitrate base. This is illustrated in Figure 36 which shows the rate of emulsion speed loss at 70°F. for Super-XX Aeronographic emulsion on both safety and nitrate base as manufactured in 1942 (when nitrate base was discontinued for Aeronographic film). In 1943, the stability of Super-XX Aeronographic emulsion itself was greatly improved, as indicated by the upper curve in Figure 36, but this degree of keeping quality could not be obtained with nitrate base.

Long-term Preservation of Negatives

Although negatives made on nitrate base are in existence which are still in reasonably good condition after many years' storage, others have become discolored, embrittled, or have deteriorated beyond use. A thorough investigation

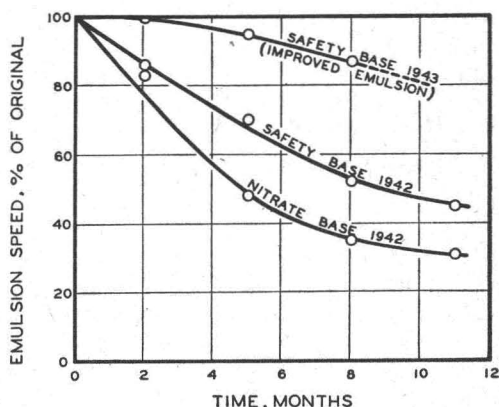


FIG. 36. The rate of emulsion speed loss for Kodak Super-XX Aeronographic Film on safety and nitrate base at 70°F., 50-60% R.H.

¹³ All Kodak safety film is edge printed with the word "Safety" for identification purposes. Information on the proper storage of nitrate film can be obtained from the National Fire Protection Association, 60 Battery March Street, Boston, Massachusetts.

of the relative chemical stability of safety and nitrate photographic film was made at the National Bureau of Standards by Hill and Weber about 1936 (22). Research on the stability and preservation of film records was also reviewed later by Scribner (23). The relative stability of the two films was studied by means of an accelerated aging test at 100°C. This test had previously been employed satisfactorily in evaluating the stability and permanence of different types of paper. It was found that safety motion picture film (regular acetate base) retained 65% of its initial folding endurance after 30 days at 100°C., and 50% after 150 days.¹⁴ Nitrate film, on the other hand, retained 50% of its initial folding endurance for only 5 days at 100°C. and after about 10 days its folding endurance was zero.

Hill and Weber also found that the acidity of nitrate film increased to a serious extent on aging at 100°C., whereas the acidity of the safety film remained low even after 30 days at this temperature. The increase in acidity of the nitrate film has serious secondary consequences because the gelatin of the emulsion is attacked and solubilized by the acids liberated. The specific viscosity of the film base, which is a measure of the degradation of the cellulose ester molecule, was also determined. After 30 days at 100°C., the nitrate film showed a decrease of 95% in specific viscosity compared with a drop of only 9% for the safety film. As a result of this investigation the authors concluded that, "while it is not possible to predict the life of acetate film from these results, the data show that the chemical stability of the film, with respect to oven-aging, is greater than that of papers of maximum purity for permanent records." Nitrate film, on the other hand, has such poor stability that it is entirely unsuitable as a permanent record material. As soon as records on nitrate film show signs of incipient deterioration, they must be copied on safety film. The vast majority of aerial negatives come under the category of valuable long-term records, and if first made on safety film, they need not be copied to ensure their preservation.

Fire Hazard

Almost everyone is aware of the fire hazard of nitrate film, but those who have never actually witnessed a nitrate film fire can hardly appreciate the ferocity and speed with which the film burns. A careless cigarette or sparks from some other source may make a raging fire of a roll of nitrate aerial film in 30 to 60 seconds (Figure 37). This is very little time for fire fighting forces to get into action, particularly if other rolls of film or combustible matter are near enough to ignite. One factor that makes a nitrate fire particularly vicious is that cellulose nitrate contains enough oxygen in the molecule to support combustion even in a confined air space and under these conditions generates dangerous pressures. In addition to the hazard to life and property from the fire itself, the fumes given off by the combustion of nitrate film are extremely toxic.

Another aspect to the hazard of nitrate aerial film is the danger it contributes to flying operations especially in wartime. Colonel G. W. Goddard, Chief, Photographic Laboratory, Wright Field, in a recent address¹⁵ showed photographs of the considerable damage done to a German airplane when an aerial camera loaded with nitrate film was hit by gunfire and exploded. Safety film under similar circumstances was merely cut into little pieces. Colonel Goddard pointed out the advantage that the United States Air Force had during

¹⁴ Modern safety base films, either motion picture or aerial, are superior in chemical stability to the regular acetate studied by the Bureau of Standards in 1936.

¹⁵ Before the Rochester Technical Section, Photography Society of America, Rochester N. Y., December 8, 1946.

the war in using only safety aerial film whereas the Germans were compelled to use nitrate.

Safety Aerographic Film will melt and burn very slowly if held in a flame from some other source, but once the flame is removed, it stops burning. For example, it required six to ten relights and considerable effort to burn the hole

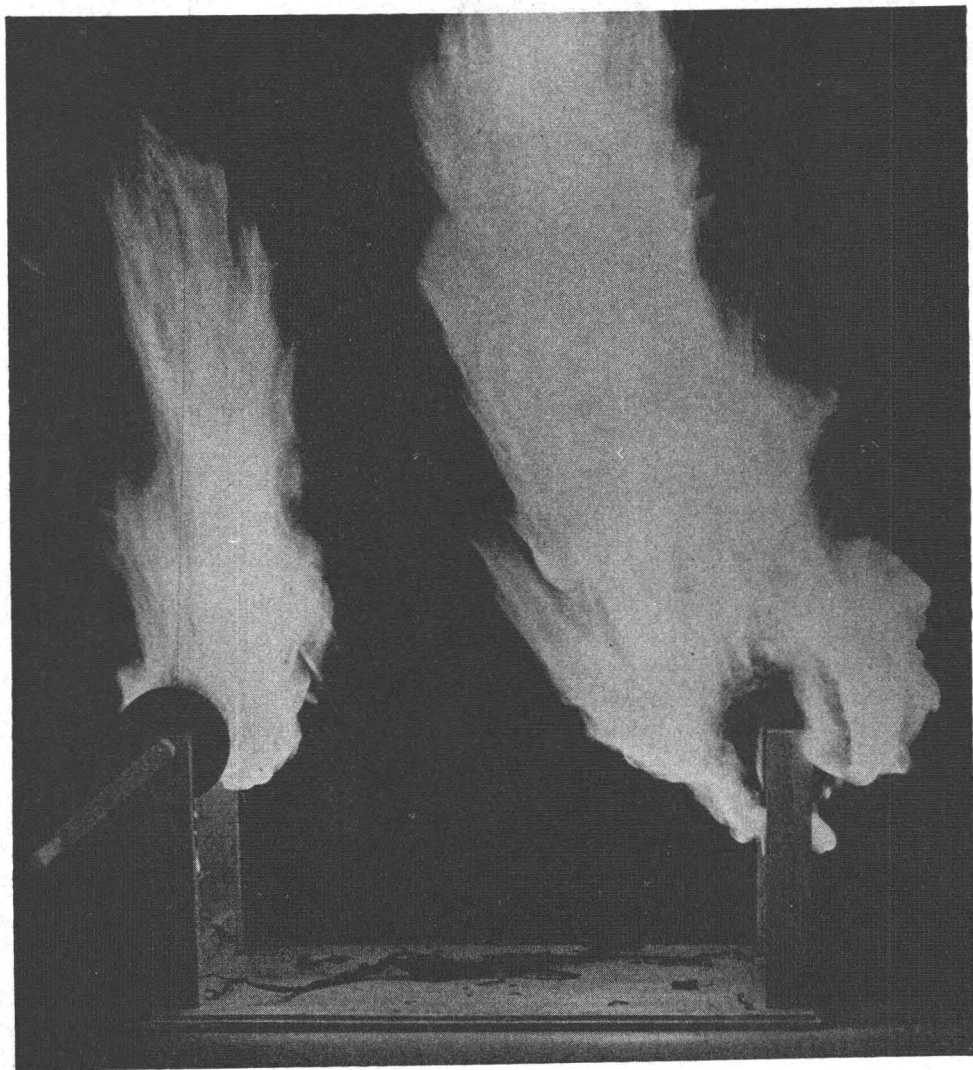


FIG. 37. Nitrate film on standard $9\frac{1}{2}$ " Aero spools on a dummy rewind, approximately 60 seconds after ignition. (About 25 feet of film on one spool; 125 feet on the other).

in the edge of the Safety Aerographic Film shown in Figure 38. This film burns with considerably greater difficulty than ordinary paper, and the fumes given off, although unpleasant, are not dangerous as are the fumes from burning nitrate film. Another point to consider is the appreciable financial saving in fire insurance and expensive fire precautions achieved by the use of safety aerial film in place of nitrate.

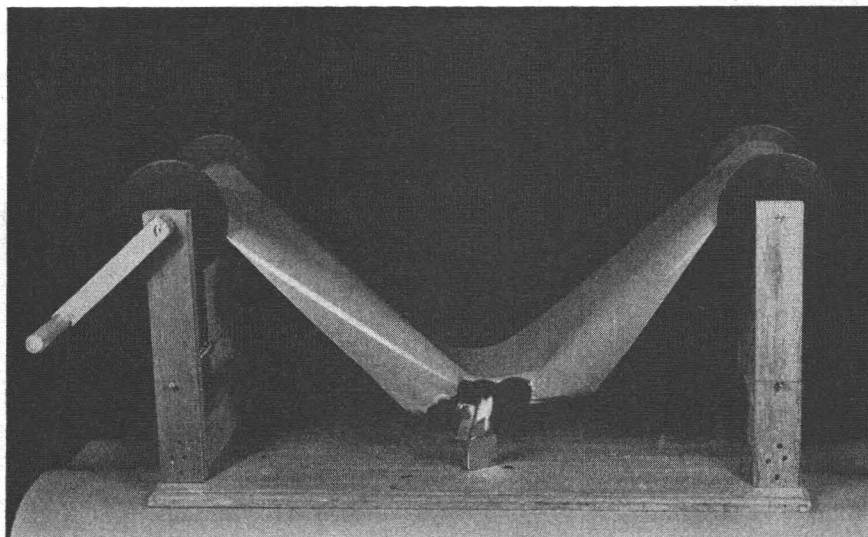


FIG. 38. Safety Aerographic Film on $9\frac{1}{2}$ " Aero spools after 6 to 10 attempts at ignition.

VIII. DISCUSSION AND CONCLUSIONS

It has been pointed out that Safety Aerographic Film base has never been made from, and should not be confused with, regular acetone-soluble cellulose acetate. Only cellulose acetate propionate, cellulose acetate butyrate and high acetyl cellulose acetate have been used and these esters all give a safety film base having superior physical properties and superior dimensional stability compared with regular acetate. Furthermore, Safety Aerographic Film base has been continually improved since it was first introduced about ten years ago.

Nitrate Aerographic Film admittedly has some advantages over Safety Aerographic Film, particularly in mechanical properties such as strength and stiffness. Nitrate Aerographic Film has very slightly lower humidity expansion and thermal expansion coefficients, but the present acetate butyrate Safety Aerographic Film (AB-284) has better uniaxialism and lower long-time shrinkage above 70°F . On the whole there is very little to choose between these two films in dimensional stability. The greatest difference between the nitrate and safety film is in chemical stability. Here the safety far outweighs the nitrate in its superior keeping qualities for the unexposed emulsion, its infinitely greater permanence for the preservation of valuable negatives, and its freedom from fire and explosion hazard. There can now be little doubt that the advantages of safety base far outweigh the disadvantages for all types of aerial photography.

The high acetyl acetate Safety Aerographic Film (HA-411) manufactured for a few months during 1946 did have considerably better mechanical properties than the acetate butyrate (AB-284), but suffered from slightly poorer uniaxialism and higher long-time shrinkage. For these and other manufacturing reasons it has not been continued. It is our hope that eventually a safety base can be made for Aerographic film which will combine the superior physical properties of the high acetyl acetate with the superior dimensional stability of the acetate butyrate. Some of the difficulties in accomplishing this objective will be appreciated when it is realized that very frequently on one property of a film base can be improved only at the expense of another.

Little hope can be offered of any major improvement in the dimensional stability of Safety Aerographic Film. Distortion and permanent shrinkage have already been reduced to the lowest possible level in the manufacturing process. In the final analysis film base is a plastic and the very word "plastic" means that a material of this type will flow under stress. It cannot be expected to compare with metal or glass in dimensional stability. That is one price we must pay for the many advantages of simultaneous flexibility and transparency.

We believe that the most fruitful way of reducing dimensional changes, including distortion, in aerial film negatives will be found in improvements in the technique of handling the film under service conditions. For example, thermal and humidity dimensional changes can be greatly minimized by proper thermostating of cameras and air conditioning of laboratories, preferably at about 70°F., 50% R.H. The importance of proper relative humidity control in all film operations cannot be overemphasized. There is undoubtedly room for improvement in processing, printing and other film manipulations. Very frequently it is found that small dimensional errors from different causes can be made to cancel each other rather than become additive. However, further investigations under actual operating conditions are needed to determine how this can best be done.

ACKNOWLEDGEMENT

The writer wishes to point out that the work described in this paper is the result of the combined efforts of a large number of people in the Department of Manufacturing Experiments and other departments of the Film Division, as well as the Research Laboratories of the Eastman Kodak Company. Dr. E. K. Carver and Mr. C. L. A. Wynd are responsible for directing the experimental work and for many helpful suggestions in the preparation of the paper. Dr. A. C. Robertson originated a number of the refined laboratory techniques employed in the evaluation of the physical properties of Aerographic film. The contributions to the paper of those who assisted in the collection of data and preparation of graphs are likewise gratefully acknowledged.

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APPENDIX

Sections relating to shrinkage and brittleness of aerial photographic film taken from Army-Navy Aeronautical Specification, "Film; Aerial Photographic," AN-F-40, 28 August 1944, and Amendment-2, 19 November, 1945.

B. TYPES

- Type IA.—Topographic
- Type IB.—Reconnaissance

E. DETAIL REQUIREMENTS

E-7. Shrinkage.—Maximum shrinkage for Type IA film shall not exceed 0.15 percent, and the maximum variation shall not exceed 0.07 percent. Maximum shrinkage for Type IB film shall not exceed 0.50 percent. The shrinkage shall be determined as specified in section F and defined in section I.

E-8. Brittleness.—When tested as specified in section F, the film shall break at an average spacing of the parallel planes not greater than 0.100 inch for both the lengthwise and widthwise direction and not more than 25 percent of the samples tested shall break at a spacing greater than 0.20 inch.

F. METHODS OF SAMPLING, INSPECTION AND TESTS

F-6. Shrinkage.—Shrinkage shall be defined as expansion and/or contraction. It shall be measured by means suitable to the Procuring Agency. At least 20 strips lengthwise and an equal number widthwise of the roll shall be cut, perforated, conditioned at 50 percent relative humidity at 70°F. (21.1°C.), and measured. After normal development and drying (not over 80°F.), the strips shall be placed at least $\frac{1}{4}$ inch apart in racks in an oven at 120°F. (49°C.) and 20 percent relative humidity for seven days. Then they shall be reconditioned thoroughly to 50 percent relative humidity at 70°F. (21.1°C.), measured, and the percent shrinkage calculated. The average shrinkage of all the test strips and the variation shall be calculated.

F-7. Brittleness.—At least 15 representative samples, one by five inches, both lengthwise and widthwise, shall be cut from the roll of raw film after conditioning to 50 percent relative humidity at 70°F. (21.1°C.). The ends of the strips shall be stapled together $\frac{1}{4}$ inch from the ends with the emulsion on the outside of the loop. The loop shall be conditioned to 14 percent relative humidity at 70°F. (21.1°C.) for at least 17 hours and not more than 24 hours. Without removing from the above mentioned atmospheric conditions, the test loop shall be placed between two parallel planes which shall be moved toward each other at a uniform rate of 0.017 inch per second until the loop of the film cracks. The loop shall be held between the staple and the ends in a clamp, with one inch jaws. The jaws shall be $\frac{3}{4}$ inch from the stationary plane surface and in the same plane. The

brittleness shall be measured as the distance between the parallel planes at the time the crack of the film is heard.

I-6. DEFINITIONS

I-6e. Shrinkage.—Shrinkage is the average of the percent of shrinkage of 20 lengthwise and 20 widthwise strips.

I-6f. Variation.—Variation is the difference between the average percent shrinkage of 20 lengthwise and 20 widthwise strips.

FORD BARTLETT MEMBERSHIP AWARD

The following proposal (quoted in part) received from Lockwood, Kessler & Bartlett, Inc., Engineers and Surveyors, 32 Court Street, Brooklyn, New York, was accepted by the Board of Direction on May 26, 1947:

"We should like to present the following proposal for consideration by your Board of Direction:

To further the objectives of and to stimulate the growth of the American Society of Photogrammetry it is proposed that in appreciation of their efforts a gold Society emblem be presented in our behalf to each member who is instrumental in securing ten new members during the period April 1st to December 31st, 1947.

The cost of the above will be paid by us as the awards, to be known as the Ford Bartlett Membership Award, are distributed."

In accordance with the expressed desire of the donor, the Secretary-Treasurer will distribute the gold emblems to individual members immediately upon their completed acquisition of ten new members.

Houston H. Bradford of Chattanooga is the only member now eligible for the award, according to records available to the Secretary-Treasurer. It is recognized that records are not sufficiently adequate to associate the names of many with new members added in recent months. A record is maintained wherever identification is possible, however, many of our new members should properly be credited to a deserving member who has brought the Society to their attention. Unfortunately our records do not provide sufficient information in this regard. By agreement with the donor, the Secretary-Treasurer will enter an appropriate credit to any member upon being advised of the names of new members for whom an individual is responsible. It should be stated that all new members resulting from the campaign "Every Member Get a Member in 1947," are eligible for inclusion in the award period.

Talbert Abrams, Professor Kenneth B. Jackson, M. Kerwin Linck, Harold J. McMillan, R. G. Sanders and John W. Simmons, according to available records, are within easy striking distance of the award. It is hoped that others who properly belong in this group will advise the Secretary-Treasurer so the records can be put in order. Lockwood, Kessler & Bartlett, Inc., have stated that they would be pleased to see a large number of awards made.