A COMPARISON OF DESIGN AND PERFORMANCE PROPERTIES FOR SELECTED AIRCRAFT FABRIC COVERING PROCESSES

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CHAPTER I

INTRODUCTION

Background

Most of the large and small aircraft in production today consist of an all-metal design manufactured with lightweight aluminum alloys and steel. An all-metal construction provides strength, durability, and excellent resistance to weathering. However, there are still small aircraft in service today that have a fabric material covering the wings, control surfaces, and fuselage. Fabric aircraft covering is strong and lightweight, but is much less tolerant to environmental factors of heat, cold, moisture, and sunlight.

Because the deterioration of fabric aircraft covering can have catastrophic consequences if failure occurs in flight, the materials, workmanship, and inspection of fabric used to cover aircraft must be in strict compliance with Federal Aviation Administration (FAA) standards. There are several *FAA approved* aircraft covering processes that use organic high-grade cotton or synthetic polyester fabrics. Each process claims to offer the best quality, strength, and resistance to environmental deterioration.

A major problem for aircraft manufacturing companies and maintenance personnel is choosing the fabric and covering method that is not only cost effective in terms of labor and material, but also provides the least weight and degradation over the service life of the aircraft.

Statement of the Problem

Characteristics of aircraft uncoated fabric, coating processes, and their relative effectiveness to reduce weathering degradation need to be evaluated. Currently, no independent study comparing these properties for selected FAA approved aircraft fabric-covering methods has been published. The presentation of test results will be a valuable reference for selecting the type of fabric-covering method to use that is appropriate to the operational environment of the aircraft.

Purpose of the Study

The purpose of this study was to examine the design and performance properties of five aircraft fabric-covering processes. The design properties compared were characteristics of *nonweathered* aircraft bare fabric and coated fabric material. The performance properties compared on samples of weathered fabric were gloss retention, yellowing, low temperature flexibility, breaking strength, and *thermal stress resistance*.

Objectives of the Study

The objectives of the study were to:

1. Perform progressive *weathering* on samples of *uncoated* and *coated* aircraft fabric covering prepared using the Grade-A cotton with Randolph dope, Ceconite with Randolph dope, Air-Tech Coatings, Cooper Superflite II, and Stits Poly-Fiber processes.

2. Perform a Gloss Test using a 60°-glossmeter on weathered samples of coated fabric.

3. Perform a spectrophotometer Yellowing Test on weathered samples of uncoated and coated fabric.

4. Perform a Low Temperature Bend Test on each weathered sample of coated fabric.

5. Perform a fabric Breaking Strength Test on weathered samples of uncoated and coated fabric.

6. Perform a Thermal Stress Test on each weathered sample of coated fabric.

7. Compare findings to discover significant differences among the uncoated fabrics and the five fabric-covering methods.

Limitations of the Study

This study is limited to:

1. Five FAA approved aircraft covering processes.

2. Grade-A cotton and polyester base fabrics.

3. Low Temperature Bend Test performance, pass or fail at -40°F, for the applied coatings at incremental stages of weathering exposure.

4. Breaking Strength Test performance of uncoated and coated fabric samples at incremental stages of weathering exposure.

5. Thermal Stress Test based upon the time to burn through a coated sample under a 0.5-lb. tension when subjected to a constant heat source of 1,250°F ± 50°.

Assumptions

The design of the study was based upon the following assumptions:

1. That reinforcing tapes, rib stitching, grommets, inspection rings, and structural attachment are beyond the scope of the research effort.

2. That the coating process applied to a test panel is homogenous. Thus, test samples taken from the test panel are representative of the covering process.

3. That accelerated weathering is not intended to be representative of actual aircraft operating conditions.

4. That test samples received from vendors in support of this research were prepared in accordance with approved data applicable to their process.

5. That thermal stress test results are not intended to be representative of actual fire-in-flight conditions.

Hypotheses

The hypotheses tested were that:

1. There is a significant difference in the gloss retention characteristics among the *process samples* due to weather degradation.

2. There is a significant difference in yellowing among the process samples due to weather degradation.

3. There is a significant difference in the breaking force among the uncoated organic cotton and synthetic polyester fabrics due to weathering.

4. There is a significant difference in the breaking force among the process samples due to weathering.

5. There is a significant difference in the breaking force among the process samples for any given exposure time.

6. There is a significant difference in the thermal stress resistance among the process samples due to weathering.

Definition of Terms

FAA Approved is defined as Federal Aviation Administration approval for a process or manufacture of parts that conform to stringent standards of safety and suitability for general aviation aircraft.

Ceconite Randolph is used in Chapter IV and Chapter V to define the use of Randolph Coating Products applied over Ceconite 101 fabric.

Coated material or fabric is used to define Randolph coatings, Air-Tech coatings, Superflite or Stits Poly-Fiber products applied over the bare fabric of Grade-A cotton or polyester fabric.

Cotton Randolph is used in Chapter IV and Chapter V to define the use of Randolph Coating Products applied over Grade-A cotton fabric.

General aviation aircraft are defined as single and multi-engine aircraft less than 12,000 pounds in weight.

Nonweathered is defined as uncoated or coated fabric that has not been subjected to weathering.

Process sample(s) is used to define coated organic cotton and coated synthetic polyester fabrics.

Thermal stress resistance is used to define the ability of a material to retain its strength when exposed to destructive heat and flame during the Thermal Stress Test. The time in seconds to burn through a sample under tension is the unit of measurement.

Uncoated material is used to define bare Grade-A cotton or polyester fabric.

Weathering is defined as material samples exposed to 4 hours of concentrated fluorescent ultraviolet light (UVA-340 lamps) and 4 hours of condensation in the QUV tester located at the University of Missouri Rolla's Coating Institute.

CHAPTER II

REVIEW OF LITERATURE

Introduction

A recent survey by Baird (1996) indicated the primary reason for the decline of participation in general aviation was high cost. This high cost was associated not only with recurring aircraft maintenance, but with initial capital investment as well. Consequently, aviators are looking at alternatives to the high capital investment required for production aircraft that include purchase of less expensive fabric covered airplanes.

Although the fabrics used to cover *general aviation aircraft* are less durable than metal, they have many advantages. Fabric covering reduces overall aircraft weight, requires minimal skill to install, and is less costly than metal. Also, owners can select either organic or synthetic type material to cover and protect their airplanes (U.S. Department of Transportation, 1988). Thus, it is extremely important to the mechanic, aircraft builder, and aviator to know the advantages and disadvantages of a particular fabric and associated coating process that is applied over the fabric.

Fabric covering information is also important to the National Air and Space Museum (NASM). In his study of aircraft preservation at NASM, Mautner (1995) noted that an artifact's original fabric condition was once a primary concern to NASM. However, measures have been taken by NASM to study aircraft fabric preservation treatments to ensure longevity of the fabric and the reduction in recurring maintenance costs.

Because of the renewed interest in fabric covered aircraft, the aviation community needs current information pertaining to aircraft covering processes. To accomplish this purpose, a review of literature is presented. First, organic and synthetic aircraft fabric and coating methods are reviewed. Next, degradation factors applicable to aircraft fabric cover are summarized. Finally, aircraft fabric tests that are used to evaluate the serviceability of installed fabric are provided.

Organic Aircraft Fabric Methods

There are two organic types of material that are used in aircraft fabric covering: linen and Grade-A cotton. The linen, sometimes called Irish linen, is an unbleached fabric that is used primarily in England where it is manufactured under British specifications (Carlson, 1978). Although the fabric possesses similar weight, strength, and threads per inch to that of Grade-A, it is much more difficult to finish (U.S. Department of Transportation, 1976).

The organic aircraft fabric used in this study is a mercerized cotton categorized as Grade-A and is manufactured to American Materials Standard (AMS) 3806E (1993). The mercerization process hardens the fabric fibers by washing the fabric in a caustic solution of soda to remove waxes (Carlson, 1978). Grade-A aircraft fabric is made of a high-grade cotton calendered to reduce its thickness and provide a smooth surface. However, it has not been pre-shrunk and will require tautening in the coating process.

Grade-A cotton is required on aircraft that have a wing loading of 9 pounds per square foot or greater and never-exceed speeds of 165 miles per hour or greater, which includes virtually all general aviation aircraft. Wing loading is important because the fabric must be strong enough to withstand the forces applied to the plane in flight. It is calculated using the relationship,

$$\text{Wing Loading} \approx \frac{\text{Aircraft Gross Weight}}{\text{Total Wing Area}} \tag{1}$$

For instance, a typical single engine general aviation aircraft having the following specifications,

Maximum gross weight:	1150 pounds
Wing span:	20 feet
Average Wing Width:	4 feet

has a wing loading that can be calculated using Equation 1 as

$$\text{Wing Loading} \approx \frac{1150 \text{ pounds}}{(20 \text{ feet})(4 \text{ feet})} \approx 14.3 \frac{\text{lb}}{\text{ft}^2} \tag{2}$$

Thus, Grade-A cotton or equivalent strength characteristics must be used on this aircraft.

Grade-A Cotton and Dope

The proper application of Grade-A cotton is essential for good appearance and long life. Carlson (1985) says that a good Grade-A or linen job should last as long as five to eight years. Grade-A cotton is typically attached to the structural members using an envelope method that consists of sewing together several widths of fabric to make an envelope or sleeve (U.S. Department of Transportation, 1976).

All Grade-A cotton fabric covering applied to an aircraft must be taut, smooth, and properly finished. The first step in the finishing or coating process is to apply a fungicidal dope to the fabric to prevent rotting (U.S. Department of Transportation, 1988). Also, according to Hall (1963) proper chemical treatment of cotton fabrics significantly preserves the strength of cotton fibers.

Since Grade-A cotton fabric has not been pre-shrunk, three to five coats of tautening dope must be applied to tighten the fabric. After tautening to the proper amount, two coats of aluminum pigmented dope are applied to reduce the effects of ultraviolet exposure degradation to the fabric base. Finally, three coats of pigmented (colored) dope are applied to complete the process (U.S. Department of Transportation, 1988).

The successful application of dope finishes on fabric depends on the temperature, humidity, correct dope mixture, and method of application (U.S. Department of Transportation, 1976). Extremes of temperature or humidity can cause dope to dry in such a condition that the fabric becomes slack. Humidity can also cause blushing in dopes. Blushing occurs when evaporation lowers surface temperatures of the freshly doped fabric causing condensation of moisture on the surface. Finally, Carlson (1985) says that precautions must be exercised when handling dope because it is flammable, and a respirator is recommended because fumes are harmful if breathed in excess.

Synthetic (Polyester) Fabric Methods

Synthetic material used in aircraft covering is composed of polyester type material. Polyester production began as early as 1928 (Ludewig, 1964) with experiments involving certain acids that were molecularly distilled in nitrogen and put in contact with a glass rod to produce fibers. It was not until the 1950s, though, that development of polyester fibers improved to a point where good mechanical strength, fire resistance, and ultraviolet stability properties were stable enough to be used in a variety of products (Sittig, 1971).

The polyesters that are available today are quite different in nature from those produced in the 1950s and 1960s (Doyle, 1969). Polyester is manufactured in various forms to meet the requirements of a wide variety of different applications. Certain reinforced polyesters have been used in the aircraft industry for both structural and non-structural component parts (Doyle & Piellisch, 1969, 1992). Failure analysis tests on composite material reinforced with woven and braided fabric performed by Nalk (1994) showed that there was a variation in the strength of the resulting composite material with fabric fiber added. In addition, Ludewig (1964) determined that polyester fibers have a very high modulus of elasticity creating excellent elastic recovery with regard to traction, pressure and flexing, characteristics favorable in the operational environment of small aircraft. Also, Ludewig (1964) found that polyester fibers had low flammability and considerable resistance to high and low temperatures. Because of the good characteristics inherent in polyester fabric, the Federal Aviation Administration (FAA) has given approval for its use as an aircraft covering when manufactured in accordance with strict standards (U.S. Department of Transportation, 1976).

This study looks at four FAA approved aircraft covering processes that use polyester based fabric:

1. Ceconite with Randolph dope
2. Air-Tech Coatings
3. Cooper Superflite II
4. Stits Poly-Fiber

These processes differ in the preparation of the fabric base and application of both protective and final coatings.

Ceconite-Randolph Dope

Ceconite, Inc. received FAA approval in 1967 for their synthetic aircraft fabric called Ceconite (Procedures Manual #101, 1960). Ceconite fabric typically has strength properties greater than that of Grade-A cotton and is approved as a replacement for that covering when installed in accordance with FAA approved Supplemental Type Certificate (STC) SA1351WE and SA2666WE.

Ceconite can be attached using an envelope or cemented method (Procedures Manual #101, 1960). The envelope method uses lacing, screws, or clips to attach the fabric to the airframe in order to duplicate the manufacturer's original method of attachment. The cemented method uses special glue to attach the Ceconite to aircraft members if the fabric width is sufficient to cover an entire surface.

Once Ceconite is attached to structural members, it is shrunk to proper tautness by a hand-held source of heat such as an iron. Proper tautness is determined when a coin bounces off the fabric when dropped from about a foot (Randolph Products Co., 1996).

To avoid distortion of airframe members caused by overshrinking and crystallization of the polyester fibers, the iron heat must remain below 425°F. After the fabric has been tautened to the proper amount, it is ready for coating.

The Randolph coating process uses nitrate and non-tautening butyrate dope to finish the Ceconite fabric (Randolph Products Co., 1996). Nitrite dope is used to bond the polyester fibers but is highly flammable due to the use of nitric acid in the material production (Carlson, 1978). Butyrate dope is made from butyric acid and is less flammable than nitrite dope (Carlson, 1978). However, butyrate dope cannot be used to attach fabric to the aircraft structure because it does not adhere well to the polyester fibers. Also, dope finishes must be applied under regulated temperature and humidity limits to prevent improper adhesion (U.S. Department of Transportation, 1976). The basic Randolph coating process is summarized below (Randolph Products Co., 1996).

1. Three coats of nitrate dope.
2. Three coats of clear butyrate dope.
3. Two coats of aluminum dope (UV protection).
4. Four cross coats of colored dope.

Air-Tech Coatings

Air-Tech is an FAA approved polyurethane coating process for application over any of the approved polyester fabrics (Air-Tech Application Procedures, 1997). The Ceconite fabric is attached to the airframe with Air-Tech proprietary fabric adhesive in a similar method as that used for the Randolph and Ceconite process. Also, the fabric is tautened using a calibrated heat source such as an iron. Once properly tightened and after all reinforcing tapes, grommets, and so forth are installed, the surface of the fabric is cleaned with Air-Tech fabric wash before primer coats are applied.

Three coats of Air-Tech primer are applied to the fabric. The first coat may be brushed if desired, and it is important to allow approximately 15 minutes between primer coats. After 12 hours, the top primer coat may be lightly sanded if needed. Finally, two or three coats of Air-Tech color are applied over the primer. Twenty to thirty minutes must be allowed between applications.

The toxic hazards reported by Davis (1997) for the urethane type paints are applicable to the Air-Tech coating process. A fresh-air source respirator and strict safety precautions are required when spraying these types of products.

Cooper Superflite II

The Superflite System II is a 100% polyurethane finishing system using Superflite 102 polyester fabric (Manual D-102A-Superflite System II, 1995). Because of the high solids, consistency of the material, and thick coating, Davis (1997) claims that fewer coats are needed.

The Superflite 102 polyester fabric is tautened in a similar way to the method for the Ceconite fabric using a calibrated heat source such as an iron. Once properly tightened, three coats of primer/filler are applied over the entire fabric. The Superflite primer/filler fills the fabric weave and provides UV protection (Manual D-102A – Superflite System II, 1995). After the fabric has been lightly sanded, two polyurethane finish coats of color are applied.

Davis (1997) states that the toxic effects of smelling fumes under this process can reach life-threatening levels if inhaled for an extended period of time. The body does not rid itself of the toxic materials used in the polyurethane process as in the case of the cellulose-based substances. Therefore, a fresh-air source respirator and strict safety precautions are required when spraying this material.

Stits Poly-Fiber

The Poly-Fiber system was introduced in 1965 and included a specially designed polyester fabric (Goldenbaum, 1997). The process is similar to the Ceconite system where the fabric is glued to the airframe, but there are significant differences in the coatings applied to the Poly-Fiber polyester fabric.

The coatings used in the Stits process are made from vinyl that has an advantage of flexibility with no shrinkage. The coatings are also easily removed by the solvent methylethyl-ketone when repairs are needed.

Once the fabric is attached to the airframe with Poly-Fiber's proprietary fabric cement Poly-Tak, it is tautened in a similar way to the method for the Ceconite fabric using a calibrated heat source such as an iron. Once properly tightened, which is at 350°F, the fabric is sealed with a brush coat of Poly-Brush fabric sealer. This process helps bond the polyester fibers and further bonds the fabric to the airframe. After the reinforcing tapes, grommets, and so forth are installed, two additional spray coats of Poly-Brush sealer are applied. The UV protection is accomplished by applying three spray coats of Poly-Spray UV blocker. Finally, two to three coats of Poly-Tone or Aero-Thane color spray are applied over the Poly-Spray UV blocker.

The toxic hazards reported by Davis (1997) for the urethane type paints are applicable to the Poly-Fiber coating process when using Aero-Thane paint finishes. A fresh-air source respirator and strict safety precautions are required when spraying these types of products. For the Poly-Tone paints, Goldenbaum (1997) says that only a respirator is recommended.

Fabric Covering Degradation Factors

There are many factors that contribute to the deterioration of aircraft fabric including air pollutants, ultraviolet light, moisture, and temperature.

Air Pollutants

Organic fabric, Grade-A cotton, deteriorates most rapidly in the presence of sulfur dioxide that is found in industrial areas (U.S. Department of Transportation, 1976). Sulfur dioxide changes into sulfuric acid when combined with oxygen, sunlight, and moisture and is extremely harmful to organic fabric (U.S. Department of Transportation, 1976). Furthermore, a study of combustion and emission pollutants for municipal solid waste (MSW) disposal processes by Hasselriis and Licata (1996), shows that combustion of MSW creates chemical reactions of oxygen, chlorine, fluorine, and sulfur that degrades organic aircraft fabric. On the other hand, polyester fabric is far more resistant to chemical emissions, but is more susceptible to ultraviolet light weakening (Doyle, 1969).

Ultraviolet (UV) Light

Doyle (1969) states that the organic and polyester fibers are harmed by ultraviolet light in wavelengths between 275,000 to 400,000 mμ. This range of ultraviolet light frequency, whether from the sun or artificial lighting, causes discoloration and subsequent loss of strength in the polyester material. In fact, Ludewig (1964) predicted that polyester fabrics lose 60% of their original strength after exposure to 2,800 hours of sunlight. In her doctoral research study, Self (1987) determined that prolonged exposure to sunlight caused damage to the chemical linkages of the polymers, resulting in loss of rigidity and strength retention.

Moisture

Moisture, on the other hand, in the form of humidity and mildew can attack organic fabrics. In an independent study by Gibson et al. (1996), woven fabrics, such as cotton, experience fiber swelling which tends to close off the pores in the fabric and restrict convective airflow through the material. In her doctoral study, Hall (1963) showed that moisture does accelerate the degradation of cotton fabric to an appreciable extent, especially during the wetting and drying cycles. Therefore, all organic fabric must be treated with a fungus inhibitor to prevent premature deterioration because of its susceptibility to fungus and mold growth (U.S. Department of Transportation, 1976). Gibson et al. (1996) also studied polyester fabrics and concluded that they are much less hygroscopic and show much less variation with relative humidity. Their results are supported by Ludewig's (1964) study of the low moisture absorption characteristics of polyester. Ludewig concluded that there was almost no difference between the tenacity and stretching values for dry or wet polyesters.

Temperature and Weathering

Additional fabric degradation factors that affect both organic and polyester fabrics are temperature and weathering (Hall, 1963). Comparative tests show the thermal stability of polyester fabrics is outstanding as compared to other fibers (Ludewig, 1964). In fact, Ludewig ascertained that polyester fibers retain more than one-quarter of their original strength at 0°C. For the organic fabrics, Hall (1963) showed that an increase in temperature has much more of an effect on cotton fibers than does an increase in humidity. Additionally, Furrow (1996) performed extensive testing of the environmental effects of temperature and humidity cycling on composite material impregnated with polyester fabric. He concluded that this cycling reduced the static strength of the material only about 10%. In a related study, Doyle (1969) claims that the combination of moisture, temperature, and air causes oxidation of the polyester material, which is an important cause of fiber weakening.

Fabric Testing Standards

Federal Aviation Administration Technical Standard Order (TSO) C15d (U.S. Department of Transportation, 1990) and the Aerospace Material Specification (AMS) 3806E (1993) contain performance standards and specifications for aircraft fabric.

Aircraft fabric manufactured after September 28, 1990 must meet the requirements of TSO C15d. This TSO authorizes the use of polyester fabric as "airplane cloth" if it has certain equivalent properties as cotton cloth. Table 1 summarizes the applicable requirements of the TSO to this study.

TABLE 1

CHARACTERISTICS OF AIRCRAFT FABRIC

Minimum Breaking Strength (lb/in^2) New	Maximum Elongation % (Nominal Width 36")	Minimum Breaking Strength (lb/in^2) Deteriorated
80	13	56

AMS 3806E (1993) specification covers manufacture and performance properties for mercerized cotton cloth that is typically used for covering aircraft surfaces. This specification is referenced in TSO C15d and contains exceptions and additions applicable to polyester type fabric. Although stronger than Grade-A cotton, the factors of Table 1 are applicable to the synthetic fabrics. Particularly, the minimum breaking strength for uncoated deteriorated polyester fabric is 56 pounds per square inch. See Table 2 (AMS 3806E, 1993).

TABLE 2

CHARACTERISTICS OF GRADE-A COTTON-UNDOPED

Minimum Breaking Strength (lb/in^2)	Elongation Under 70 Pound Tension % Maximum (Nominal Width 36")		Minimum Breaking Strength (lb/in^2)	Thread Count Per Inch
New	Warp	Fill	Deteriorated	
80	13	11	56	80 Min/84 Max

Summary

Aircraft fabric-covering processes differ greatly in the type of coatings used to cover the bare fabric. The traditional and most classic method uses a Grade-A cotton fabric impregnated with various layers of dope including a pigmented coat for UV protection. This method uses no hazardous materials and is the easiest to repair. However, cotton fabric does not weather well and will require rejuvenation or replacement sooner than the polyester methods. Polyester processes use stronger polyester fabric that is prepared using specific instructions. These processes include: Ceconite with Randolph Dope, Air-Tech Coatings, Cooper Superflite II and Stits Poly-Fiber. Each of these methods differs significantly in the types of materials used to cover and protect the fabric, and the exposure to hazardous material. Finally, all aircraft fabric must be periodically tested to ensure the environmental effects of heat, cold, sunlight, and moisture have not degraded the fabric to an unsafe condition.

CHAPTER III

METHODOLOGY

Introduction

The review of literature indicates that there is ample information available regarding the physical properties of cotton and polyester aircraft fabric. Because of the durability and resistance to weathering of polyester aircraft fabric, it is far more popular than cotton. However, virtually no information exists comparing the effectiveness of each process to protect the fabric from weathering degradation.

This chapter outlines the procedures for the research and incorporates the assumptions and limitations of Chapter I. It is organized into three primary areas: preparation of fabric samples, laboratory procedures for testing the samples, and the method of statistical analysis needed to quantify the data. Finally, although Grade-A cotton and dope is not a popular covering method today, it is included in the study for two reasons. First, Grade-A cotton was the first aircraft fabric approved by the FAA and is still referenced in Technical Standard Orders pertaining to aircraft fabric. Secondly, use of Grade-A cotton will provide a good baseline in comparing the polyester type fabric and coating processes.

Fabric Specimen Preparation

Fabric Samples

Aircraft fabric and coating material for the Grade-A cotton and Ceconite with Randolph dope were obtained from Univair Aircraft Corporation located in Aurora, CO. The Superflite II fabric and coating material were obtained from the vendor. Prepared samples for the Stits and Air-Tech coatings were received from respective vendors. Each piece of fabric was attached to a square frame and tautened. Frames were labeled with the type of fabric and covering process. Small amounts of uncoated Grade-A cotton, Ceconite, Superflite, and Poly-Fiber fabric were set aside for weathering tests of the uncoated fabric. Table 3 illustrates the composition of the samples, frames, and corresponding process to be used.

TABLE 3

SAMPLE FRAME COMPOSITION

Frame	Aircraft Fabric	Covering Process
1	Grade-A Cotton	Grade-A Cotton & Dope
2	Ceconite 101	Ceconite-Randolph Dope
3	Superflite 102	Cooper Superflite II
N/A – Vendor Provided	Ceconite 102	Air-Tech Coatings
N/A – Vendor Provided	Poly-Fiber P-103	Stits Poly-Fiber

Each fabric square, Frames 1-3, was coated with material required by each covering process. A final white color coat, Insignia White, was selected because discoloration from weathering is easily seen with this type of pigment.

After 10 days of curing, 4"x7" fabric samples were cut from the fabric of each frame and labeled to accommodate the accelerated weathering exposure apparatus.

Method of Accelerated Weathering

The accelerated weathering exposure tests were made using a Fluorescent UV-Condensation Exposure apparatus manufactured under the trade name QUV. The QUV chamber used for this study is located at the University of Missouri-Rolla (UMR) Coatings Institute and operated under the supervision of the Director, Dr. Michael Van De Mark. Dr. Van De Mark and his assistant Nicole Mason made this study possible by the donation of their time and university resources.

The QUV chamber at UMR can accommodate a maximum of sixty-four 4"x7" samples that are divided equally between two testing racks. The QUV can be programmed to regulate weathering in an operation cycle of 8 hours: four hours of concentrated UV exposure followed by a 4-hour water condensation. Because of the need to allow room for other research projects, one rack was allocated to this research effort.

A total of fifty 4"x7" samples of fabric were conditioned in the university's QUV chamber and monitored every 100 hours of exposure to detect changes in gloss and color. Samples of each fabric were removed from the test chamber after 400-hour exposure intervals with the final set accumulating 2000 hours of exposure. A test matrix associated with the testing is summarized in Table 4.

TABLE 4

QUV EXPOSURE TESTING OF FABRIC SAMPLES

Sample Source	Sample Size	QUV Exposure (Hours)				
		400	800	1200	1600	2000
Cotton Randolph	4"x7"	X	X	X	X	X
Ceconite Randolph	4"x7"	X	X	X	X	X
Air-Tech	4"x7"	X	X	X	X	X
Superflite	4"x7"	X	X	X	X	X
Stits	4"x7"	X	X	X	X	X
Cotton*	4"x7"	X	X	X	X	X
Ceconite*	4"x7"	X	X	X	X	X
Superflite*	4"x7"	X	X	X	X	X
Poly-Fiber*	4"x7"	X	X	X	X	X

Note: X denotes required tests * denotes uncoated fabric

Laboratory Procedures

The design properties compared were characteristics of nonweathered aircraft bare fabric and coated fabric material. The performance properties compared on process samples of weathered material were gloss retention, yellowing, low temperature flexibility, breaking strength, and thermal stress resistance. ASTM Standards D2136-94, Standard Test Method for Coated Fabrics–Low Temperature Bend Test. D5035-95, Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method), and E162-94, Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source, were used as guidance in this research.

Design Properties

Fabric Material. For each uncoated and nonweathered fabric material, elongation and breaking strength were tested using guidance provided in ASTM D5035-95, Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method). The sample characteristics to be obtained are summarized in Table 5.

TABLE 5

NONWEATHERED AND UNCOATED FABRIC CHARACTERISTICS

Fabric Type	Elongation Under 57 lb. Tension %	Breaking Strength
Cotton	*	*
Ceconite	*	*
Superflite	*	*
Poly-Fiber	*	*
Mean μ	*	*
Standard Deviation σ	*	*

Note: * denotes data to be obtained

Fabric Coating Material. For each nonweathered and uncoated sample, thickness was measured using a digital micrometer. Both thickness and weight were measured for the five nonweathered process samples using a digital micrometer and balance scale respectively. The characteristics to be obtained are summarized in Table 6.

TABLE 6

NONWEATHERED FABRIC CHARACTERISTICS

Sample Source	Thickness (in.)	Weight (lb/ft^2)
Cotton Randolph	*	*
Ceconite Randolph	*	*
Air-Tech	*	*
Superflite	*	*
Stits	*	*
Mean μ	*	*
Standard Deviation σ	*	*
Cotton**	*	
Ceconite**	*	
Superflite**	*	
Poly-Fiber**	*	

Note: * denotes data to be obtained
** denotes uncoated fabric

Performance Properties

Gloss Test. Using a 60°-glossmeter, the University of Missouri Rolla's Coating Institute performed a coating Gloss Test on each process sample throughout the QUV weathering cycle. The Gloss Test provides an indication of changes to the coating surface due to weathering. At each weathering interval, the 60°-glossmeter reading was recorded for each of the process samples and statistically analyzed to determine the differences among the coating processes.

Yellowing Test. Using a spectrophotometer, the University of Missouri Rolla's Coating Institute performed a coating Yellowing Test on each process sample throughout the QUV weathering cycle. The Yellowing Test provides an indication of changes to the coating surface due to weathering. At each weathering interval, the spectrophotometer yellowing index reading was recorded for each of the uncoated fabric samples and the five process samples. Data were statistically analyzed to determine the differences among the uncoated fabric and process samples.

Low Temperature Bend Test. A Low Temperature Bend Test was accomplished on each weathered process sample using the guidelines outlined in ASTM D2136-94, Standard Test Method for Coated Fabrics—Low Temperature Bend Test. This pass or fail test evaluates the stiffening properties of material when exposed to low ambient temperatures. The coated sample is cooled and conditioned at a temperature of -40°F, removed from the cooling chamber, and immediately bent around a 5/16" mandrel. The coating passes the test if no cracks are detected under a 5x-power magnification. At each weathering interval, the results of the Low Temperature Bend Test were recorded.

Graphically, the *Pass or Failure* vs. *Hours of QUV Exposure* data were plotted for all the weathered samples to illustrate the differences among the processes.

Breaking Strength Test. A Breaking Strength Test was accomplished on each weathered sample using the guidelines outlined in ASTM D5035-95, Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method) and U.S. Department of Transportation (1976) AC65-15A. Figure 1 and Figure 2 illustrate the apparatus used for this research, and its operation.

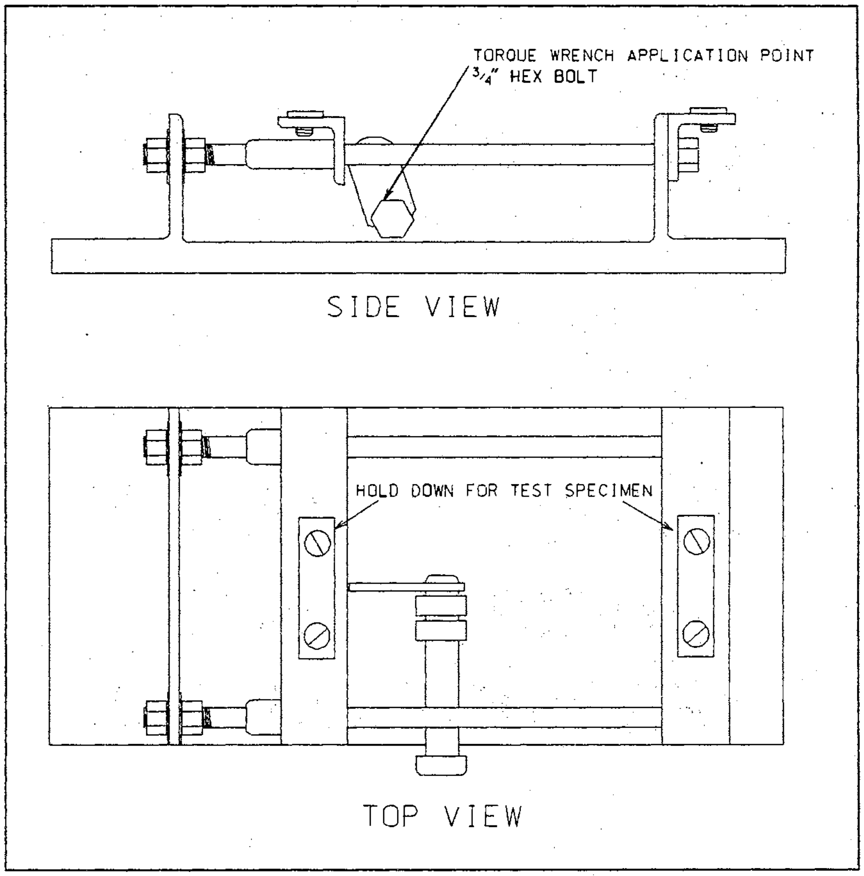

Figure 1. Fabric Breaking Strength Tester

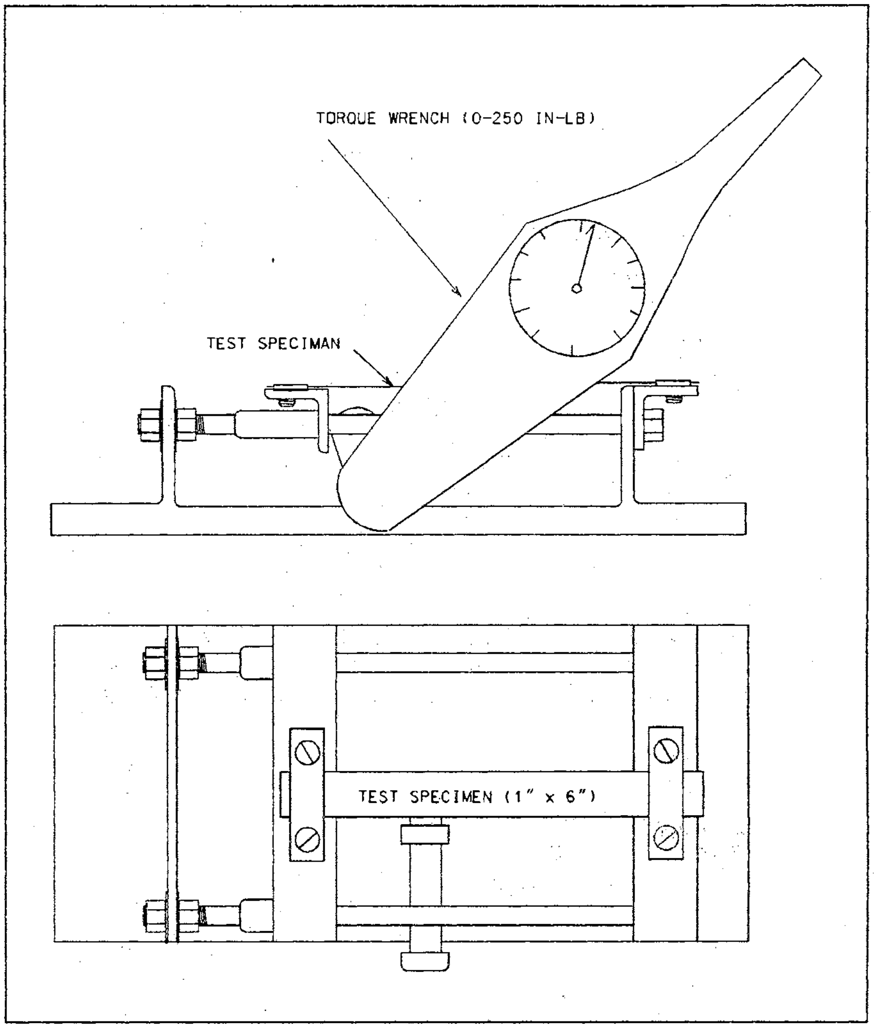

Figure 2. Fabric Breaking Strength Tester Operation

The first step in using the testing apparatus is to securely clamp the fabric sample to the unit. Care must be taken when attaching the fabric to the hold down clamps to ensure that no damage occurs to the sample at the clamp edges. The test begins when a constant counter-clockwise torque is applied by the dial torque wrench to the ¾" hex bolt. This places a tension on the 1" x 6" specimen. As the fabric breaks, the "following needle" on the torque wrench stays at the maximum value on the dial. Since the moment arm on the test unit is 1", the force applied to the test specimen is the reading on the torque wrench. At each weathering interval, the results of the Breaking Strength Test were recorded. Data were statistically analyzed to determine the differences among the uncoated fabric and process samples.

Thermal Stress Test. A Thermal Stress Test was accomplished on each weathered process sample using the guidelines outlined in ASTM E162-94, Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source. Figure 3 illustrates the apparatus used for this research.

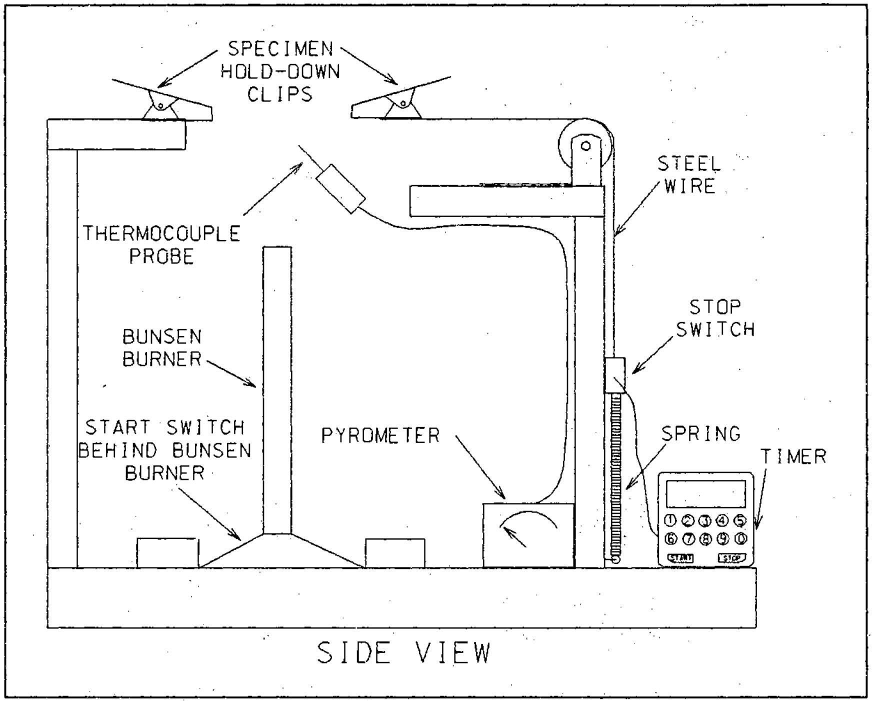

Figure 3. Thermal Stress Test Apparatus

This test provides a means to determine the thermal stress resistance of a coated sample by recording the elapsed time to burn through the material under a 0.5 lb. tension when exposed to 1,250°F ± 50° at the base fabric surface. As the Bunsen burner flame is positioned with its flame tip ¾" below the fabric base, a micro-switch is closed. Closure of this switch starts the timer for the test. When the sample burns completely through, the relaxed tension in the steel wire and spring causes the stop switch to close, ending the timed event. At each weathering interval the time to ignite and burn through a 2"x 1" section of material obtained from each weathered process sample was recorded. Data were statistically analyzed to determine the differences among the processes due to weather degradation.

Method of Statistical Analysis

Both descriptive and inferential statistics were used in this study. The design properties, which are characteristics of the nonweathered aircraft fabrics and coated material, were compared using descriptive statistics. Differences were easily seen between the statistical means and standard deviations of the design properties. As a result, meaningful comparisons were made between the processes.

The performance properties of gloss, yellowing, breaking strength, and thermal stress resistance were analyzed using inferential statistics. The performance property of low temperature flexibility was analyzed using descriptive statistics due to the nature of the data. Thus, the hypotheses of Chapter I were accepted or rejected using the Analysis of Variance (ANOVA) method (Mendenhall & Kapur, 1986,1977).

Analysis of Variance

Since there were five processes to compare, the Analysis of Variance is extended to the multiple case in order to test the null hypothesis,

$$H_0 : \mu_1 = \mu_2 = \cdots = \mu_k \tag{3}$$

where,

μ_k = Mean of the *k*th experiment

Consequently, a one-tailed *F* statistic expression is presented as

$$F > F_\alpha \tag{4}$$

The null hypothesis of Equation 3 is rejected if the *F* value of Equation 4 is large in the rejection region α.

The degrees of freedom in Equation 4 are based upon the relationships

$$v_1 = (k - 1) \tag{5}$$

$$v_2 = \left(\sum_{i=1}^{k} n_i - k \right) \tag{6}$$

where,

k = Number of experiments compared

n = Number of observations in each process or experiment

However, *F* of Equation 4 can also be expressed as

$$F = \frac{MST}{MSE} \tag{7}$$

where,

MSE = Mean squares of the experiment (unbiased estimator of σ^2)

MST = Mean squares of the total of all the experiments

Mathematically, the mean squares of the experiment, MSE, and mean squares of the total, MST, can be expressed by the equations

$$MSE = \frac{SSE}{n_1 + n_2 + \cdots + n_k - k} \tag{8}$$

$$MST = \frac{SST}{k - 1} \tag{9}$$

where,

SSE = Sum of the squares of deviations

SST = Sum of the squares of treatments

Mathematically, the sum of the squares of deviations, SSE, and sum of the squares for the treatment, SST, are expressed as

$$SSE = \sum_{i=1}^{k} \sum_{j=1}^{n_i} \left(y_{ij} - \overline{T}_i \right)^2 \tag{10}$$

$$SST = \sum_{i=1}^{k} \frac{T_i^2}{n_i} - CM \tag{11}$$

where,

T_i = Total for the observations in the *i*th sample

$\overline{T}_i$ = Mean total for the observations in the *i*th sample

CM = Correction for the mean

The correction for the mean, CM, is expressed by the equation

$$CM = \frac{(\text{total of all observations})^2}{n} = \frac{\left(\sum_{i=1}^{k}\sum_{j=1}^{n_i} y_{ij}\right)^2}{n} = n\bar{y}^2 \tag{12}$$

where,

$\bar{y}$ = Mean of all observations

n = Total number of observations

Analysis of Variance – Process Comparisons Due to Weathering Example.

Consider five covering processes that are tested for breaking strength at each 400 hours of weathering in the QUV tester, Table 7. It is desired to know if the data indicates a difference in the breaking strength for the processes over the weathering cycle at a desired significance level of $\alpha = 0.05$. The null hypothesis of Equation 3 is stated as, “There is no significant difference in the breaking strength among each of the processes due to weathering.” Thus, the hypothesis is tested using the *F* parameter of Equation 7.

TABLE 7

DATA FOR ANALYSIS OF VARIANCE–PROCESS COMPARISONS DUE TO WEATHERING EXAMPLE (DATA ARE IN LB.)

Hours of Exposure	Covering Process 1	Covering Process 2	Covering Process 3	Covering Process 4	Covering Process 5
0	110	160	115	95	105
400	100	125	90	90	70
800	80	100	85	87	55
1200	73	90	81	79	40
1600	76	70	77	51	30
2000	30	56	66	5	2
T_i	469	601	514	407	302
n_i	6	6	6	6	6
$\overline{T}_i$	78.17	100.17	85.67	67.83	50.33

First, the correction for the mean, CM, is calculated by using Equation 12.

$$\text{CM} = \frac{(\text{total of all observations})^2}{\text{n}} = \frac{(2{,}293)^2}{30} = 175{,}261.63 \tag{13}$$

SSE and SST, with *k*=5 and *n* = 6, are calculated by using Equation 10 and Equation 11.

$$\text{SSE} = \sum_{i=1}^{5}\sum_{j=1}^{6}\left(y_{ij} - \overline{T}_i\right)^2$$

$$= 3{,}844.83 + 7{,}160.83 + 1{,}363.33 + 5{,}952.83 + 6{,}253.33 \tag{14}$$

$$= 24{,}575.15$$

$$\text{SST} = \sum_{i=1}^{k}\frac{T_i^{\,2}}{n_i} - \text{CM} = \sum_{i=1}^{5}\frac{T_i^{\,2}}{n_i} - 175{,}261.63$$

$$= 183{,}701.83 - 175{,}261.63 \tag{15}$$

$$= 8{,}440.20$$

Substituting the results of Equation 14 and Equation 15 into Equation 8 and Equation 9, the values of MSE and MST to be used in the *F* parameter of Equation 7 are calculated as

$$\text{MSE} = \frac{\text{SSE}}{n_1 + n_2 + \cdots + n_k - k} = \frac{24{,}575.17}{(6+6+6+6+6)-5} = 983.01 \tag{16}$$

$$\text{MST} = \frac{\text{SST}}{k-1} = \frac{8{,}440.20}{5-1} = 2{,}110.05 \tag{17}$$

Finally, substituting Equation 16 and Equation 17 into Equation 7, the *F* parameter is calculated.

$$F = \frac{\text{MST}}{\text{MSE}} = \frac{2{,}110.05}{983.01} = 2.15 \tag{18}$$

The degrees of freedom are calculated using Equation 5 and Equation 6.

$$v_1 = (k - 1) = 5 - 1 = 4 \tag{19}$$

$$v_2 = \left(\sum_{i=1}^{k} n_i - k \right) = 30 - 5 = 25 \tag{20}$$

The *F* distribution for the values of Equation 19 and Equation 20 are shown in Table 8 for $F(\alpha{:}v_1, v_2)$ (Mendenhall, 1986).

TABLE 8

SIGNIFICANCE LEVELS FOR F(0.05:4,25)

α	$F\alpha$
0.100	2.18
0.050	2.76

Thus, comparing the *F=2.15* value of Equation 18 to the $F\alpha$ values in Table 8, the null hypothesis would be accepted for a significance level of $\alpha = 0.05$.

A table of summary information related to Analysis of Variance computations for this example is shown in Table 9.

TABLE 9

ANALYSIS OF VARIANCE –PROCESS COMPARISONS DUE TO WEATHERING EXAMPLE

	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.05}$ Table	Hypothesis	
						Accept	Reject
Between	8,440.20	4	2,110.05	2.15	2.76	X	
Error	24,575.17	25	983.01				
Hypothesis	There is no significant difference in breaking strength among the processes due to weathering.						

Analysis of Variance – Process Comparisons For Any Given Exposure Time Example. The data contained in Table 7 can be rearranged to provide additional comparisons and hypotheses testing, Table 10. In this case, it is desired to know if the data indicates a difference in the mean values of the breaking strengths for any given QUV exposure time at a desired significance level of $\alpha = 0.05$. Now, the null hypothesis of Equation 3 is stated as, "There is no significant difference in the breaking strength among the processes for any given exposure time."

Using Equation 5 through Equation 12, the summary Analysis of Variance table is constructed, Table 11. Note that the degrees of freedom are different than those of Table 7 because of the transposing of row and column values.

TABLE 10

DATA FOR ANALYSIS OF VARIANCE – PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME EXAMPLE (DATA ARE IN LB.)

	QUV Hours of Exposure					
	0	400	800	1200	1600	2000
Covering Process 1	110	100	80	73	76	30
Covering Process 2	160	125	100	90	70	56
Covering Process 3	115	90	85	81	77	66
Covering Process 4	95	90	87	79	51	5
Covering Process 5	105	70	55	40	30	2
T_i	585	475	407	363	304	159
N_i	5	5	5	5	5	5
$\overline{T}_i$	117.00	95.00	81.40	72.60	60.80	31.80

TABLE 11

ANALYSIS OF VARIANCE – PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME EXAMPLE

	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.05}$ Table	Hypothesis	
						Accept	Reject
Between	21,331.37	5	4,266.27	8.76	2.62		X
Error	11,684.00	24	486.83				
Hypothesis:	There is no significant difference in breaking strength among the processes for any given exposure time.						

The Analysis of Variance information contained in Table 9 and Table 11 shows that two different hypotheses can be tested from a single set of data. To permit easier interpretation and comparisons of the results, a composite table that combines both analyses is constructed and shown in Table 12. Hypothesis-A refers to the analysis from the data of Table 9 and Hypothesis-B refers to the analysis from the data of Table 11. This table format will be used for statistical comparisons of actual data contained in Chapter IV and Chapter V.

TABLE 12

COMBINED ANALYSIS OF VARIANCE – EXAMPLE

<table>
<tr><th colspan="8">PROCESS COMPARISONS DUE TO WEATHERING</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-A</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>8,440.20</td><td>4</td><td>2,110.05</td><td rowspan="2">2.15</td><td rowspan="2">2.76</td><td rowspan="2">X</td><td rowspan="2"></td></tr>
<tr><td>Error</td><td>24,575.17</td><td>25</td><td>983.01</td></tr>
<tr><td>Hypothesis-A</td><td colspan="7">There is no significant difference in breaking strength among the processes due to weathering.</td></tr>
<tr><th colspan="8">PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-B</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>21,331.37</td><td>5</td><td>4,266.27</td><td rowspan="2">8.76</td><td rowspan="2">2.62</td><td rowspan="2"></td><td rowspan="2">X</td></tr>
<tr><td>Error</td><td>11,684.00</td><td>24</td><td>486.83</td></tr>
<tr><td>Hypothesis-B</td><td colspan="7">There is no significant difference in breaking strength among the processes for any given exposure time.</td></tr>
</table>

The Analysis of Variance hypothesis testing of Table 11 and Hypothesis-B from Table 12 indicates that there is a significant difference in breaking strength among the processes for any given exposure time because of the rejection of the null hypothesis, H_0. This information is useful, but it does not provide any insight into the extent of the differences between weathering intervals. Thus, it becomes necessary to conduct additional analyses to determine the exact nature of the relationship between weathering times for the process variables.

Tukey's Honest Significant Difference (HSD) Test

The Tukey's HSD test provides additional hypothesis testing to determine the nature of process relationships between pairs of means after the null hypothesis has been rejected. Dixon's (1983) presentation of Tukey's multiple range test method uses the *q*-distribution (range of sample means) for estimating the difference in the population means. Tukey's theorem states, "For random samples from *k* normal populations with the same variance, the chance that all contrasts simultaneously satisfy

$$\frac{-q_{1-\alpha}s_p}{\sqrt{n}} < (a_1\overline{X}_1 + \cdots + a_k\overline{X}_k) - (a_1\mu_1 + \cdots + a_k\mu_k) < \frac{q_{1-\alpha}s_p}{\sqrt{n}} \tag{21}$$

is equal to $1-\alpha$," where the value of $q_{1-\alpha}$ is read from statistical tables of Studentized Range Values. Equation 21 establishes a confidence interval for the data. However, a more straightforward approach exists to do Tukey's HSD Testing that does not involve the calculations contained in Equation 21 (Jaccard, 1983). Jaccard states the HSD test involves the computation of a critical difference, CD, which is defined by the equation

$$CD = q\sqrt{\frac{MS_{Within}}{n}} \tag{22}$$

where,

q = Value obtained from Studentized Range Value Table for $\alpha=0.05$ significance level

n = Number of data points within a process

MS_{Within} = Mean square error (MSE from Equation 8)

The null hypothesis of Equation 3 is extended to the special case,

$$H_0 : \mu_1 = \mu_2 \tag{23}$$

where,

μ_{1-2} = Paired means for all combinations of processes

To evaluate the null hypothesis of Equation 23, the calculated critical difference value from Equation 22 is compared to the absolute difference between sample means for all paired combinations of the groups. This is much like the hypothesis testing using the *F* statistic. Thus, if

$$|\mu_1 - \mu_2| < CD \tag{24}$$

then the null hypothesis of Equation 23 is accepted and the analysis concludes with the relationship that the mean differences between the groups is not significant.

Tukey's HSD Test – Weathering Times Comparison Example. Since the data of Table 10 leads to rejection of the null hypothesis, Tukey's HSD test is applied to the data. The value of q in Equation 22 is determined with reference to three concepts: the α level, the degrees of freedom of the MSE, and the number of groups, k. Using the Studentized Range Value tables from Jaccard (1983), q is calculated by the equation,

$$q(k, df_{MSE}) = q(6,24) = 4.37 \tag{25}$$

where,

df_{MSE} = Degrees of Freedom for MSE from Table 10

Equation 22 is used to calculate the critical difference value,

$$CD = q\sqrt{\frac{MS_{Within}}{n}} = 4.37\sqrt{\frac{486.83}{5}} = 43.12 \tag{26}$$

Next, all possible pairs of exposure time data are compared using Equation 24. A table of summary information related to Tukey's HSD Test computations for this example is shown in Table 13. This table format will be used for statistical comparisons of Tukey's HSD Test data contained in Chapter IV and Chapter V.

TABLE 13

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME EXAMPLE

	QUV Hours 0	QUV Hours 400	QUV Hours 800	QUV Hours 1200	QUV Hours 1600	QUV Hours 2000	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
μ_{Hours}	117.0	95.0	81.4	72.6	60.8	31.8			Accept	Reject
COMPARISONS	μ_1	μ_2					22.0	43.12	X	
	μ_1		μ_2				35.6	43.12	X	
	μ_1			μ_2			44.4	43.12		X
	μ_1				μ_2		56.2	43.12		X
	μ_1					μ_2	85.2	43.12		X
		μ_1	μ_2				13.6	43.12	X	
		μ_1		μ_2			22.4	43.12	X	
		μ_1			μ_2		34.2	43.12	X	
		μ_1				μ_2	63.2	43.12		X
			μ_1	μ_2			8.8	43.12	X	
			μ_1		μ_2		20.6	43.12	X	
			μ_1			μ_2	49.6	43.12		X
				μ_1	μ_2		11.8	43.12	X	
				μ_1		μ_2	40.8	43.12	X	
					μ_1	μ_2	29.0	43.12	X	

H_0: There is no significant difference in breaking strength among the processes between each exposure time.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject
$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

The data of Table 13 indicate rejection of five paired hypotheses for Tukey's probability table. This information suggests that the breaking strength differences for the processes significantly decreases after 1200 hours of QUV weathering. Thus, by using Tukey's HSD Test, additional comparison information can be extracted from the test data.

Gloss Test

A Gloss Test was performed on each process sample. The data collected at each interval was given an index number reading from the 60°-glossmeter. Graphically, the *Gloss Index* vs. *Hours of QUV Exposure* was plotted for all the weathered process samples. The Analysis of Variance for the collected data allowed hypothesis testing for the claims made in Chapter I. A significance level of 0.05 was chosen for acceptance or rejection of the null hypothesis.

Yellowing Test

A Yellowing Test was performed on each process sample. The data collected at each interval was given an index number reading from the spectrophotometer that indicated the amount of surface yellowing of the sample. Graphically, the *Yellowing Index* vs. *Hours of QUV Exposure* was plotted for the weathered process samples. The Analysis of Variance for the collected data allowed hypothesis testing for the claims made in Chapter I. A significance level of 0.05 was chosen for acceptance or rejection of the null hypothesis.

Breaking Strength Test

A Breaking Strength Test was performed on the weathered uncoated and coated fabric samples. The data collected at each interval was the pounds of force needed to completely tear the sample. Graphically, the *Breaking Force* vs. *Hours of QUV Exposure* were plotted for all the weathered samples. The Analysis of Variance for the collected data allowed hypothesis testing for the claims made in Chapter I. A significance level of 0.05 was chosen for acceptance or rejection of the null hypothesis.

Thermal Stress Test

A Thermal Stress Test was performed on each weathered process sample. The data collected at each interval of exposure was the elapsed time to burn through a coated sample of material under a 0.5 lb. tension when exposed to 1,250°F ± 50° at the base fabric surface. Graphically, the *Time-to-Break (sec.)* vs. *Hours of QUV Exposure* was plotted for all the weathered process samples. The Analysis of Variance for the collected data allowed hypothesis testing for the claims made in Chapter I. A significance level of 0.05 was chosen for acceptance or rejection of the null hypothesis.

CHAPTER IV

FINDINGS

Introduction

The chapter presents a report and analysis of the data gathered during the study. It is organized into two major areas: design properties and performance properties. The data are presented in tables with accompanying charts and graphs for complete representation of information.

Design Properties

Fabric Material

For each uncoated and nonweathered fabric material, initial elongation and breaking strength test results are shown in Table 14. The data of Table 14 indicates that all uncoated fabric samples meet the maximum elongation percentage, 13% from Table 1 in Chapter II. Cotton fabric had the least elongation at 6.1% and Ceconite 101 fabric had the greatest percentage of elongation at 10.3%. The mean of 8.08% with a standard deviation of 1.49 indicates little variability among the fabrics.

The data also indicates that all the uncoated fabric samples exceed the minimum breaking strength, 80 lb. from Table 1 in Chapter II, permissible by TSO C15d. The weakest fabric was Cotton at 85 lb. and the strongest was Ceconite 101 at 190 lb.

TABLE 14

INITIAL NONWEATHERED AND UNCOATED FABRIC CHARACTERISTICS

Fabric Type	Elongation Under 57 lb. Tension %	Breaking Strength (lb.)
Cotton	6.1	85
Ceconite	10.3	190
Superflite	7.9	135
Poly-Fiber	8.0	120
Mean μ	8.08	132.50
Standard Deviation σ	1.49	37.83

Because of the large spread in data, the mean value of 132.5 lb. and standard deviation of 37.83 placed both of these fabrics outside the ± 1-σ point. Thus, there was a significant variability in the initial breaking strength among the uncoated fabric samples. Figure 4 graphically shows the comparisons of elongation for the uncoated fabric samples, and Figure 5 graphically shows the comparisons of initial breaking strength for the uncoated fabric samples used in this study.

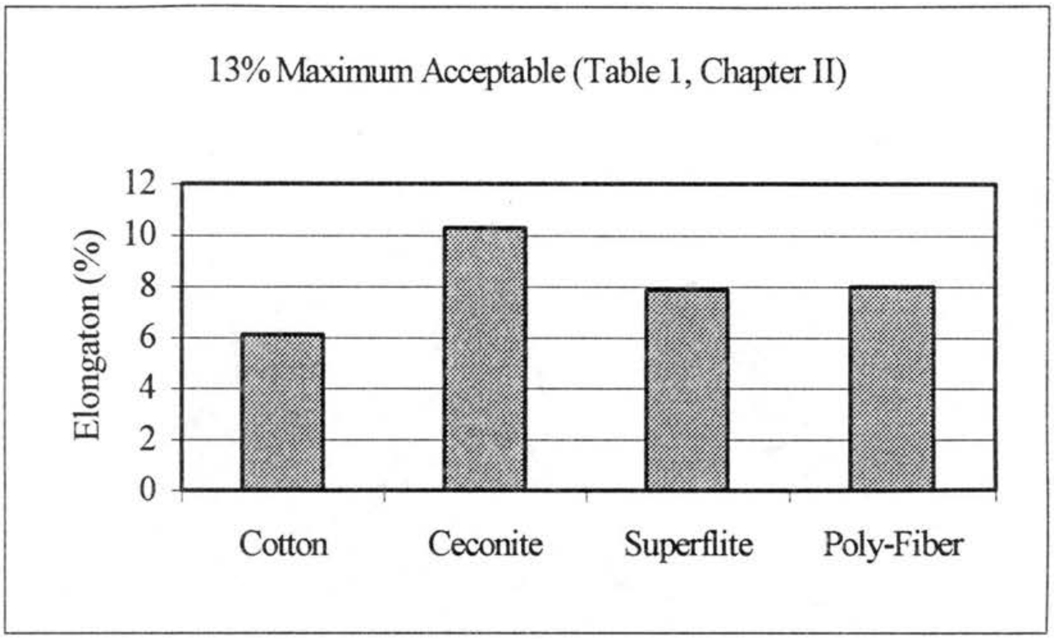

Figure 4. Elongation of Uncoated Fabric Samples

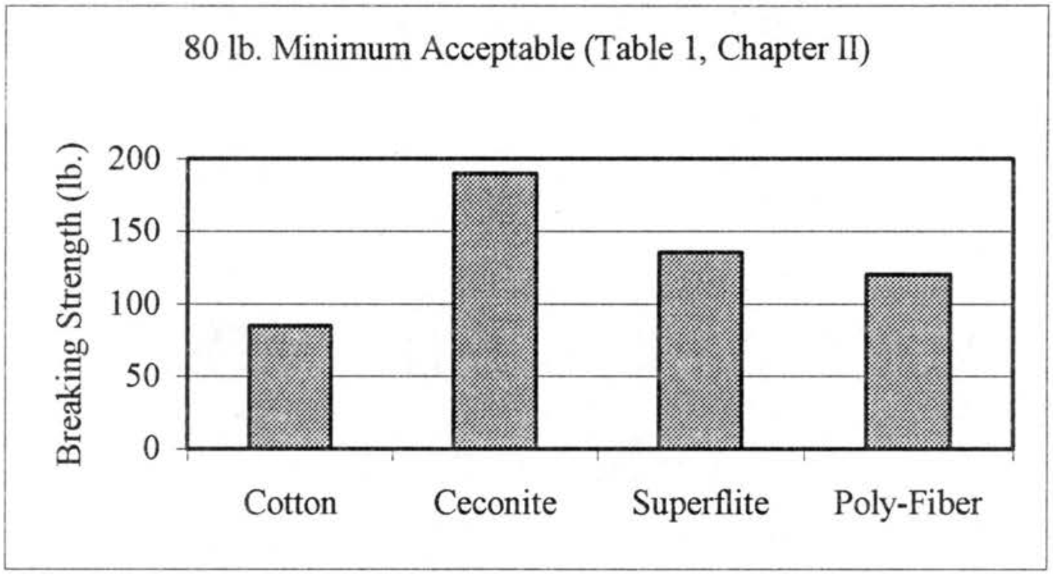

Figure 5. Initial Breaking Strength of Uncoated Fabric Samples

Fabric Coating Material

For each nonweathered sample, initial thickness and weight were measured, Table 15. Although bare Cotton fabric is the thickest at 0.0085", the mean value of 0.0061" with a standard deviation from the mean value of 0.0017" indicates very little variance.

TABLE 15

NONWEATHERED SAMPLE CHARACTERISTICS

Sample Source	Thickness (in.)	Weight (lb/ft^2)	J-3 Cub Weight (lb.)
Cotton Randolph	0.0165	0.0890	66.8
Ceconite Randolph	0.0140	0.0778	58.4
Air-Tech	0.0145	0.1175	88.2
Superflite	0.0185	0.1367	102.7
Stits	0.0110	0.0827	62.1
Mean μ	0.0145	0.0977	75.6
Standard Deviation σ	0.0027	0.0238	19.0
Cotton*	0.0085		
Ceconite*	0.0060		
Superflite*	0.0050		
Poly-Fiber*	0.0050		
Mean μ	0.0061		
Standard Deviation σ	0.0017		

Note: * denotes uncoated fabric

Of the uncoated polyester fabrics, Ceconite was only 0.0010" thicker than Superflite and Poly-Fiber. For the processed samples, Stits was the thinnest at 0.0110", and Superflite was the thickest at 0.0185". Both were approximately one standard deviation from the mean value of 0.0145", which indicates about 20% variance from the average. Figure 6 graphically shows thickness comparisons for the nonweathered fabric samples, and Figure 7 graphically shows thickness comparisons for the nonweathered process samples.

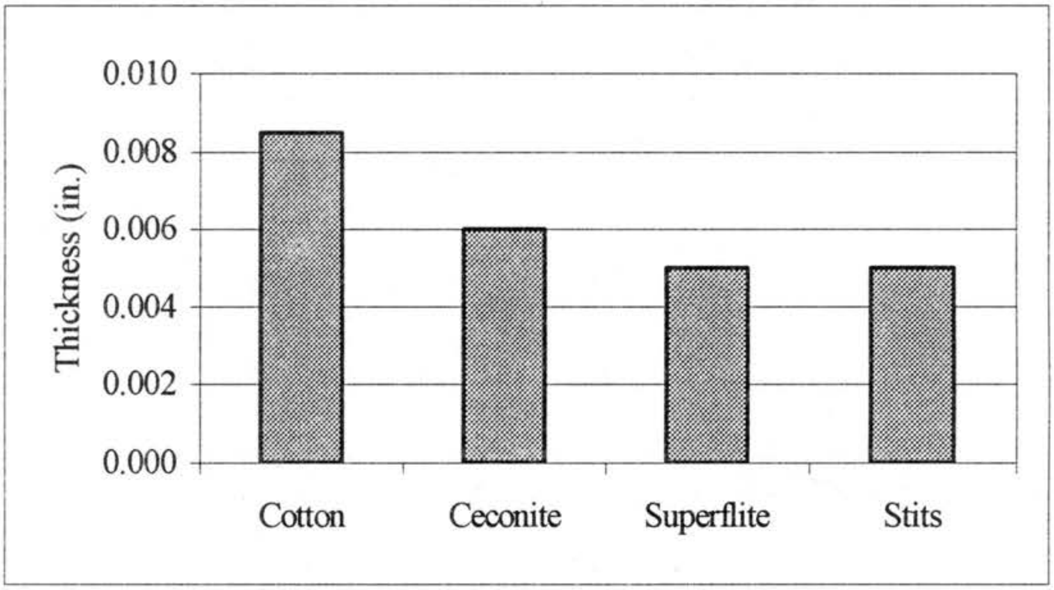

Figure 6. Thickness of Uncoated-Nonweathered Fabric Samples

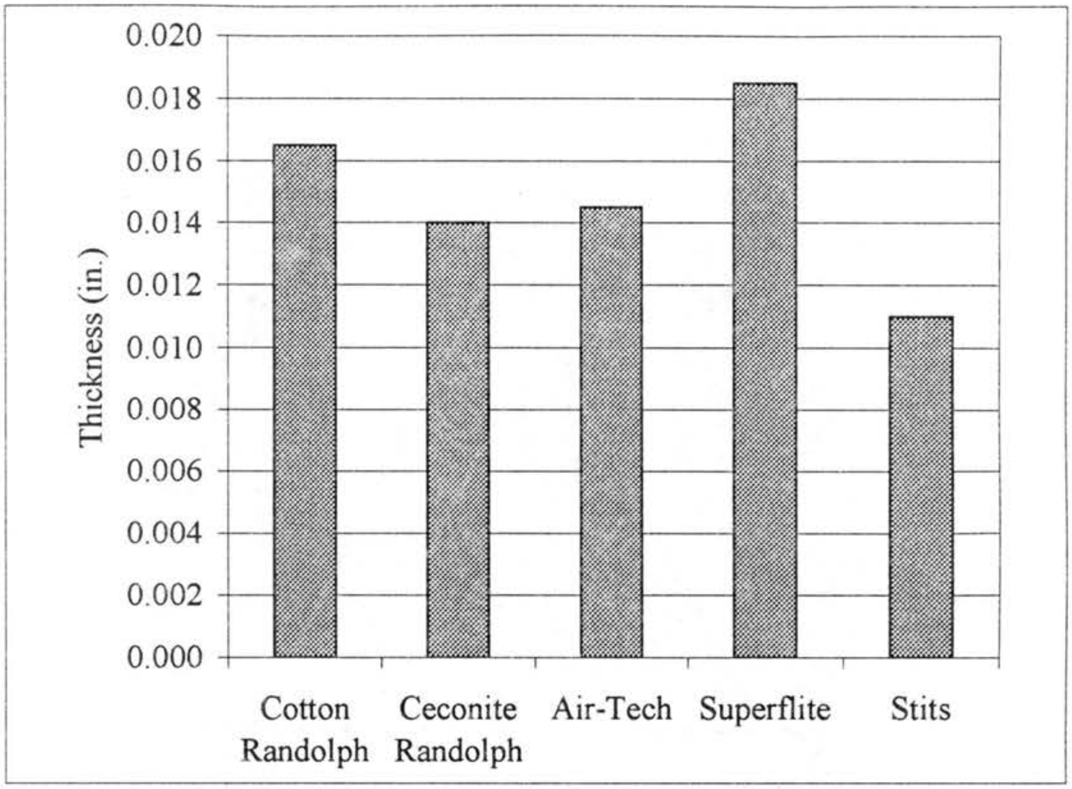

Figure 7. Thickness of Nonweathered Process Samples

The data of Table 15 also indicates that the Ceconite with Randolph dope was the lightest at 0.0778 lb/ft^2, and Superflite was the heaviest at 0.1367 lb/ft^2. A mean of 0.0977 lb/ft^2 with a standard deviation of 0.0238 indicates considerable variability in weight. This variability is more understandable if the weight-per-square-foot values are translated to a total aircraft weight for the type of covering process used. Included within Table 15 is a column titled "J-3 Cub Weight," which is the approximate weight of coated fabric if the respective process was used to cover this airplane. The J-3 Cub contains approximately 751 square feet of fabric area. The mean of 75.6 lb. with a standard deviation of 19.0 lb. shows considerable variance; this indicates that Superflite weighed almost 25 lb. more than the average and over 44 lb. heavier than the Ceconite with

Randolph dope coating. Figure 8 graphically shows the weight comparisons for the nonweathered and coated process samples. Additionally, the Air-Tech and Superflite process sample weights shown in Figure 8 are much heavier per square foot than the other samples.

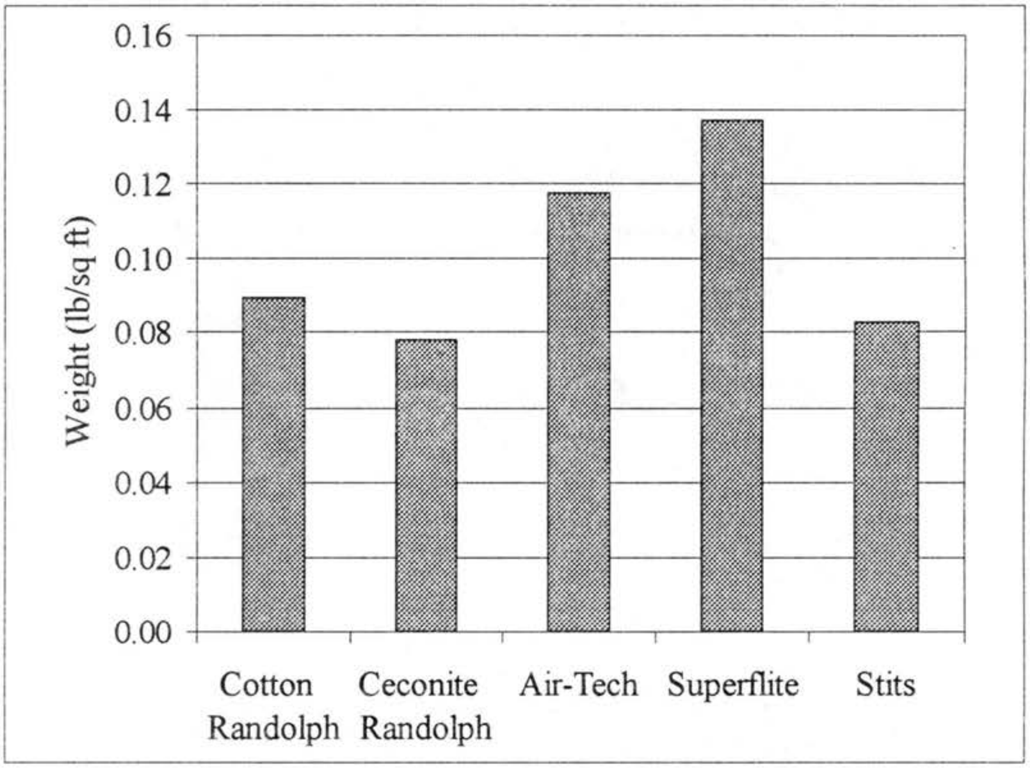

Figure 8. Weight of Nonweathered Process Samples

Performance Properties

Gloss Test

Using a 60°-glossmeter, the University of Missouri Rolla's Coating Institute performed a coating Gloss Test on each process sample throughout the QUV weathering cycle at 100-hour intervals. The Gloss Test provides an indication of changes to the coating surface due to weathering. The average gloss readings for each weathering interval are noted in Table 16.

TABLE 16

GLOSS INDEX – WEATHERED PROCESS DATA

QUV Hours	Cotton Randolph	Ceconite Randolph	Air-Tech	Superflite	Stits
0	39.94	37.26	94.26	94.54	92.26
400	35.52	29.74	78.66	89.48	71.64
800	15.53	13.30	84.50	88.90	78.18
1200	10.43	11.20	69.03	82.43	62.60
1600	15.10	16.20	71.40	79.20	44.90
2000	7.80	10.80	67.30	80.70	43.30

The data of Table 16 is graphically displayed in Figure 9 and indicates deterioration in gloss retention for all QUV weathered process samples. However, Superflite samples maintained the highest gloss retention, while the Randolph coatings on the Grade-A cotton and Ceconite fabric performed most poorly over the weathering cycle.

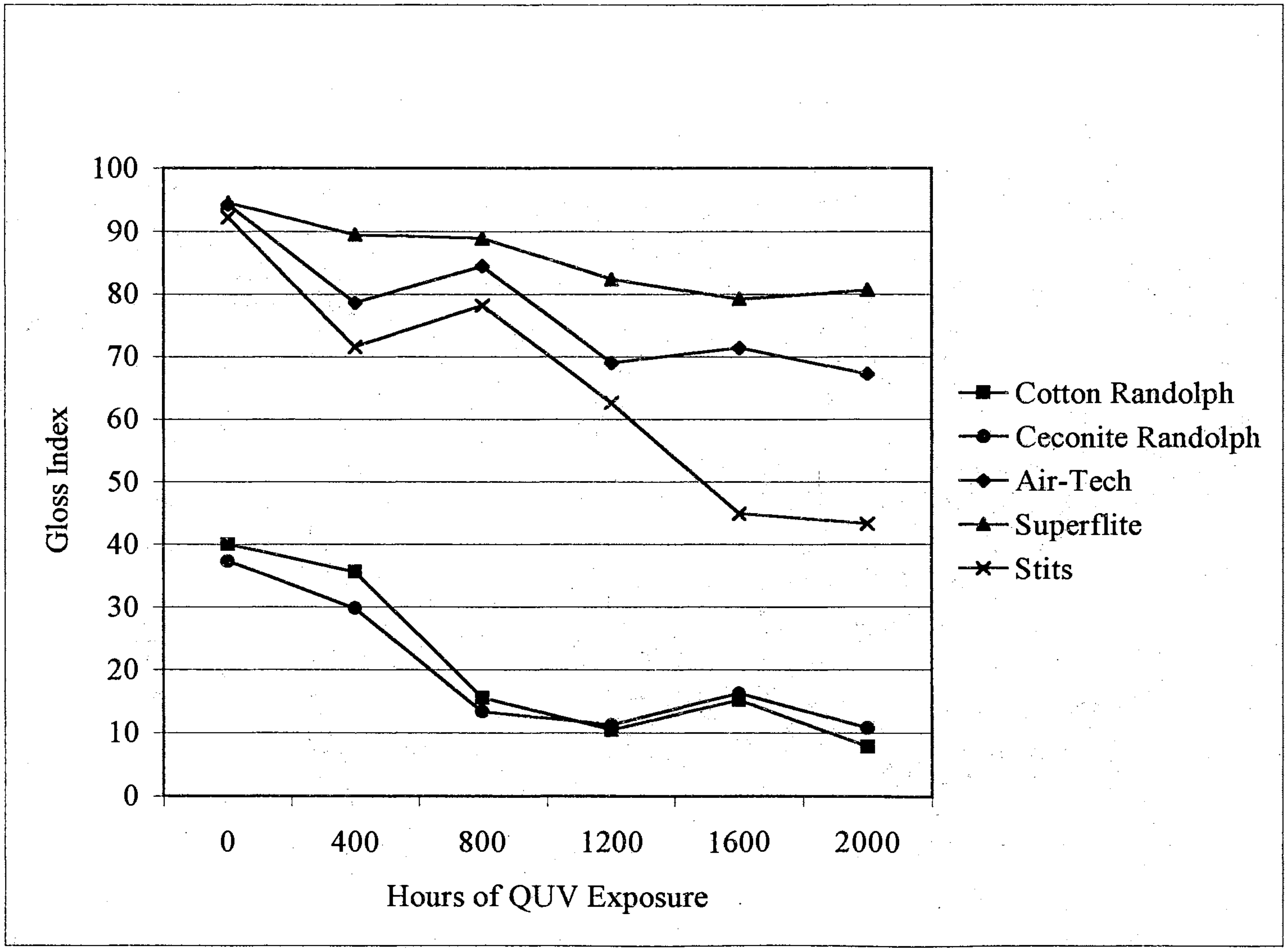

Figure 9. Gloss Index – Weathered Process Samples

To determine if there was a significant difference in the gloss retention characteristics among the process samples due to weather degradation, Hypothesis 1 in Chapter I, the Analysis of Variance on the data in Table 16 was accomplished. The results of that analysis are summarized in Table 17 and indicate a significant difference among the process due to weathering. Thus, Hypothesis 1 in Chapter I is accepted since Hypothesis-A of Table 17 is its null hypothesis, H_0. However, an Analysis of Variance on process comparisons for any given exposure time, Hypothesis-B of Table 17, indicates there was no significant difference in gloss retention among the processes for any given exposure time.

TABLE 17

ANALYSIS OF VARIANCE – GLOSS TEST OF WEATHERED PROCESS SAMPLES

<table>
<tr><th colspan="8">PROCESS COMPARISONS DUE TO WEATHERING</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-A</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>23,890.61</td><td>4</td><td>5,972.65</td><td rowspan="2">36.43</td><td rowspan="2">2.76</td><td rowspan="2"></td><td rowspan="2">X</td></tr>
<tr><td>Error</td><td>4,098.44</td><td>25</td><td>163.94</td></tr>
<tr><td>Hypothesis-A</td><td colspan="7">There is no significant difference in gloss retention among the processes due to weathering.</td></tr>
<tr><th colspan="8">PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-B</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>3,155.78</td><td>5</td><td>631.16</td><td rowspan="2">0.61</td><td rowspan="2">2.62</td><td rowspan="2">X</td><td rowspan="2"></td></tr>
<tr><td>Error</td><td>24,833.27</td><td>24</td><td>1,034.72</td></tr>
<tr><td>Hypothesis-B</td><td colspan="7">There is no significant difference in gloss retention among the processes for any given exposure time.</td></tr>
</table>

Because the Hypothesis-A of Table 17 was rejected, Tukey's Honest Significant Difference Test was applied to the data. The results of the analysis are illustrated in Table 18 and provide two possibilities for the hypothesis rejection. First, the data suggests that there is no significant difference in gloss retention neither among the Air-Tech, Superflite, and Stits processes nor between Grade-A cotton and Ceconite with Randolph dope. Second, there is a significant difference in gloss retention between products prepared with Randolph dope, and those prepared with the polyurethane coatings used by Air-Tech, Superflite, and Stits.

TABLE 18

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – GLOSS TEST PROCESS COMPARISONS DUE TO WEATHERING

	Cotton Randolph	Ceconite Randolph	Air Tech	Superflite	Stits	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
Means (μ)	20.72	19.75	77.53	85.88	65.48			Accept	Reject
COMPARISONS	μ_1	μ_2				0.97	21.34	X	
	μ_1		μ_2			56.81	21.34		X
	μ_1			μ_2		65.16	21.34		X
	μ_1				μ_2	44.76	21.34		X
		μ_1	μ_2			57.78	21.34		X
		μ_1		μ_2		66.13	21.34		X
		μ_1			μ_2	45.73	21.34		X
			μ_1	μ_2		8.35	21.34	X	
			μ_1		μ_2	12.05	21.34	X	
				μ_1	μ_2	20.40	21.34	X	

H_0: There is no significant difference in gloss retention between each process pair due to weathering.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject
$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

Yellowing Test

Using a spectrophotometer, the University of Missouri Rolla's Coating Institute performed a coating Yellowing Test on each process sample throughout the QUV weathering cycle. The Yellowing Test provides an indication of changes to the coating surface due to weathering. The average spectrophotometer yellowing readings for each weathering interval are noted in Table 19.

TABLE 19

YELLOWING INDEX – WEATHERED PROCESS DATA

QUV Hours	Cotton Randolph	Ceconite Randolph	Air-Tech	Superflite	Stits
0	8.23	8.77	10.14	9.60	7.56
400	10.57	11.06	11.92	9.87	8.40
800	10.49	10.92	11.89	10.04	8.25
1200	10.09	11.61	12.06	10.04	8.19
1600	9.94	12.27	11.81	10.01	8.01
2000	10.37	13.25	11.74	10.14	7.78

The data of Table 19 is graphically displayed in Figure 10 and indicates a general increase in yellowing for all processes through 400 hours of QUV weathering. There is also an indication of yellowing decreasing for all the polyurethane process samples toward the end of the exposure period. Furthermore, Stits samples maintained the lowest yellowing index throughout the weathering cycle.

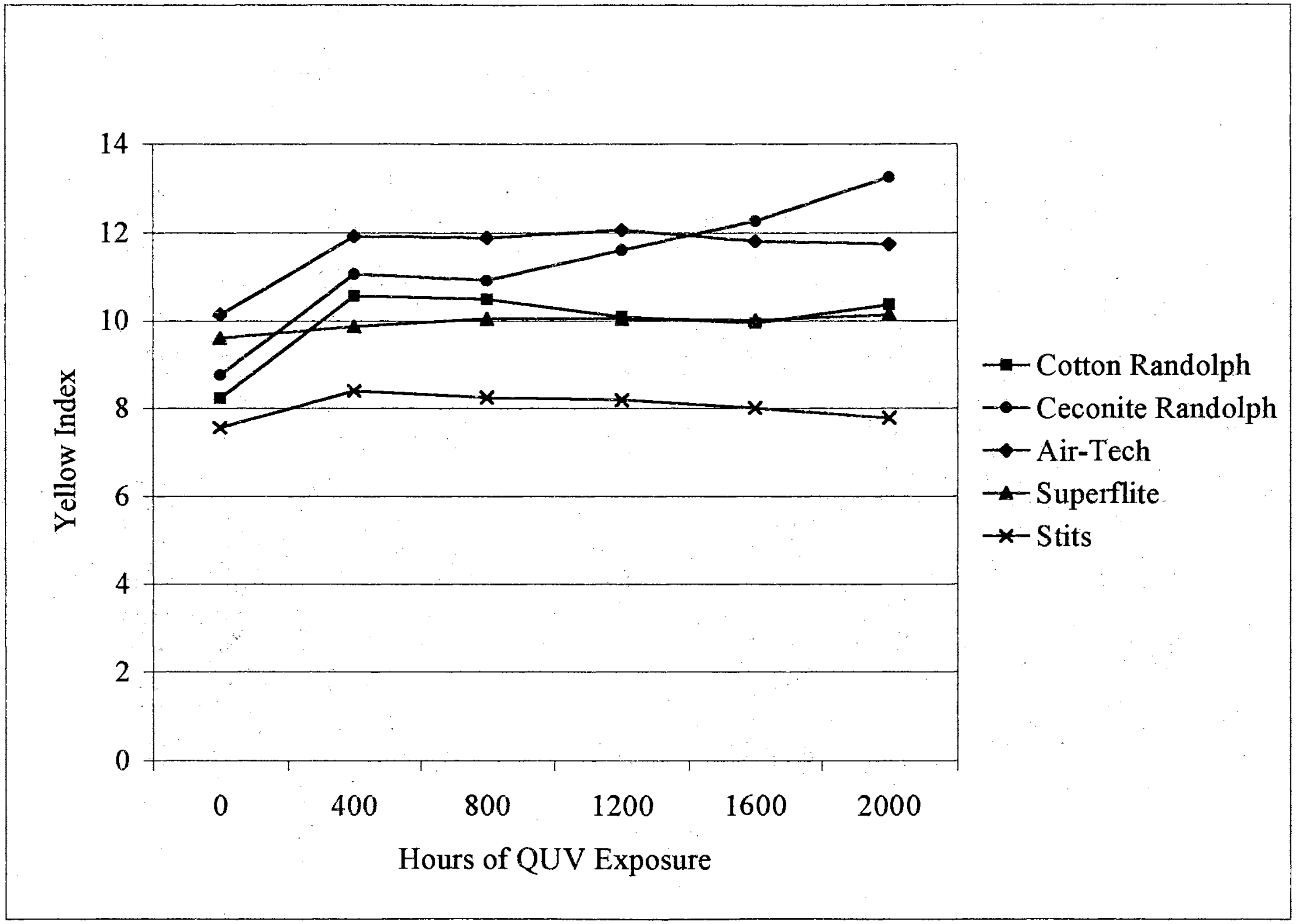

Figure 10. Yellowing Index - Weathered Process Samples

To determine if there was a significant difference in coating yellowing characteristics among the process samples due to weather degradation, Hypothesis 2 in Chapter I, the Analysis of Variance on the data of Table 19 was accomplished. The results of that analysis are summarized in Table 20 and indicate a significant difference in yellowing among the processes due to weathering. Thus, Hypothesis 2 in Chapter I is accepted, since the Hypothesis-A of Table 20 is its null hypothesis, H_0. However, an Analysis of Variance on process comparisons for any given exposure time, Hypothesis-B of Table 20, indicates there was no significant difference in yellowing among the processes for any given exposure time.

TABLE 20

ANALYSIS OF VARIANCE – YELLOWING TEST OF WEATHERED PROCESS SAMPLES

PROCESS COMPARISONS DUE TO WEATHERING

	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.05}$ Table	Hypothesis-A	
						Accept	Reject
Between	48.02	4	12.00	16.18	2.76		X
Error	18.54	25	0.74178				
Hypothesis-A	There is no significant difference in yellowing among the processes due to weathering.						

PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME

	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.05}$ Table	Hypothesis-B	
						Accept	Reject
Between	10.60	5	2.12	0.91	2.62	X	
Error	55.96	24	2.33				
Hypothesis-B	There is no significant difference in yellowing among the processes for any given exposure time.						

Because the Hypothesis-A of Table 20 was rejected, Tukey's Honest Significant Difference Test was applied to the data. The results of that analysis are illustrated in Table 21 and provide at least four reasons for the hypothesis rejection. First, the data suggests that Stits samples yellowed the least over the weathering cycle, having the lowest mean of 8.03. Second, there is no significant difference in yellowing among the Grade-A cotton with Randolph dope, Ceconite with Randolph dope, Air-Tech, and Superflite processes. Third, the data implies that Air-Tech yellows more than Grade-A Cotton with Randolph dope, Superflite, and Stits processes. Fourth, there is no significant difference in yellowing between products prepared with Randolph dope and those prepared with the polyurethane coatings used by Air-Tech, Superflite, and Stits.

TABLE 21

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – YELLOWING TEST PROCESS COMPARISONS DUE TO WEATHERING

	Cotton Randolph	Ceconite Randolph	Air Tech	Superflite	Stits	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
Means (μ)	9.95	11.31	11.59	9.95	8.03			Accept	Reject
COMPARISONS	μ_1	μ_2				1.36	1.46	X	
	μ_1		μ_2			1.64	1.46		X
	μ_1			μ_2		0.00	1.46	X	
	μ_1				μ_2	1.92	1.46		X
		μ_1	μ_2			0.28	1.46	X	
		μ_1		μ_2		1.36	1.46	X	
		μ_1			μ_2	3.28	1.46		X
			μ_1	μ_2		1.64	1.46		X
			μ_1		μ_2	3.56	1.46		X
				μ_1	μ_2	1.92	1.46		X

H_0: There is no significant difference in yellowing between each process pair due to weathering.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject

$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

Low Temperature Bend Test

A Low Temperature Bend Test was accomplished for each weathered process sample using guidance provided in ASTM D2136-94, Standard Test Method for Coated Fabrics—Low Temperature Bend Test. This pass or fail test evaluates the stiffening properties of material when exposed to low ambient temperatures. The coating sample is cooled and conditioned at a temperature of -40°F then removed from the cooling chamber and immediately bent around a 5/16" mandrel. The coating passes the test if no cracks are detected under a 5x-power magnification. The average results of the Low Temperature Bend Test for each weathering interval are noted in Table 22.

TABLE 22

LOW TEMPERATURE BEND TEST – WEATHERED PROCESS DATA

QUV Hours	Cotton Randolph	Ceconite Randolph	Air-Tech	Superflite	Stits
0	PASS	PASS	FAIL	PASS	FAIL
400	PASS	PASS	FAIL	PASS	FAIL
800	PASS	PASS	FAIL	FAIL	FAIL
1200	PASS	FAIL	FAIL	FAIL	FAIL
1600	PASS	FAIL	FAIL	FAIL	FAIL
2000	PASS	FAIL	FAIL	FAIL	FAIL

The data of Table 22 is graphically displayed in Figure 11 for all the processes and indicates that there are significant differences in low temperature flexibility among the sample coatings. The Cotton with Randolph dope performed the best with no

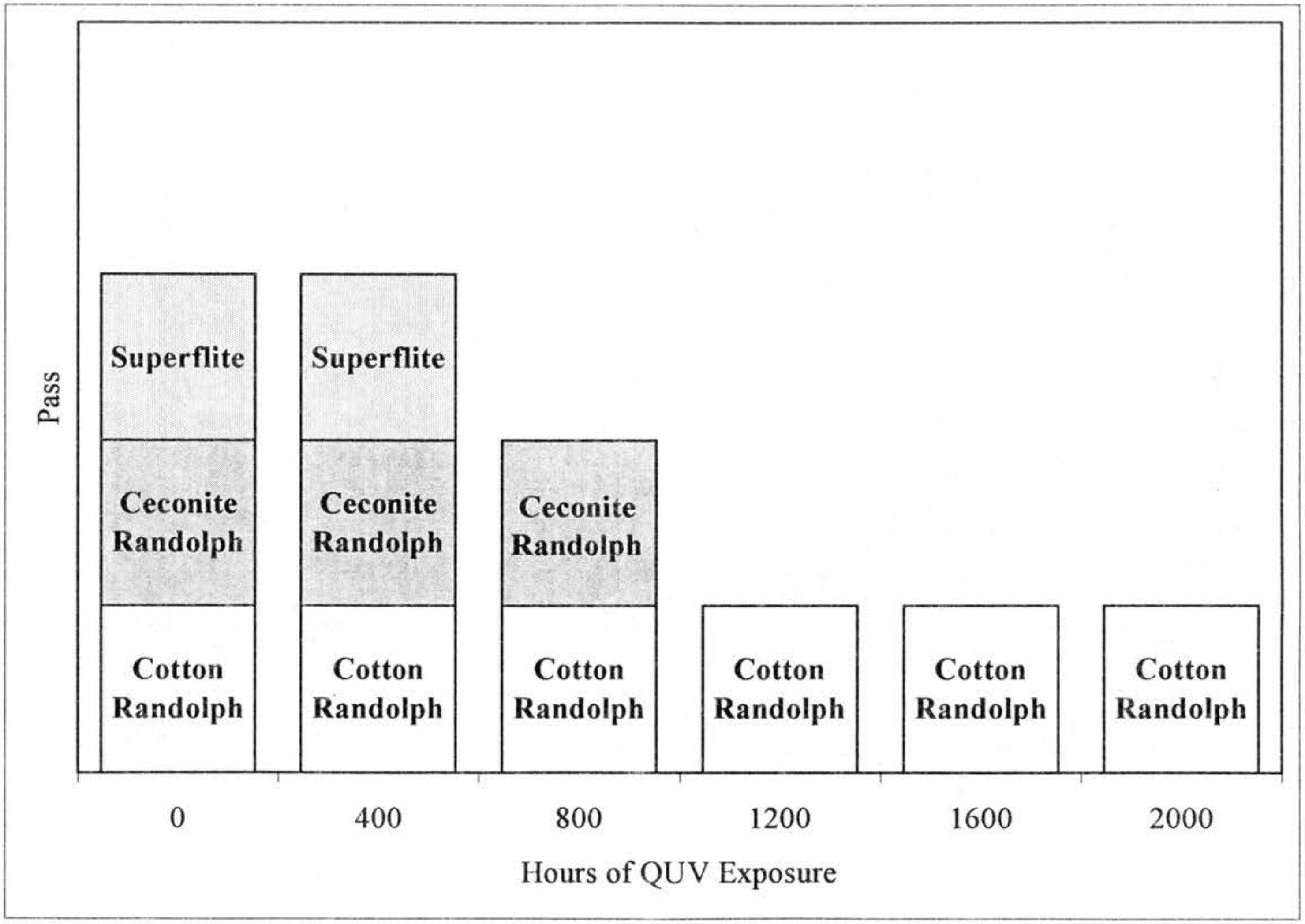

Figure 11. Low Temperature Bend Test – Weathered Process Samples

failures at each weathering interval. Ceconite with Randolph dope passed through 800 hours of QUV weathering. Superflite was the only polyurethane based coating process that passed any of the weathering intervals; this was at the initial and 400 hour exposure times.

Breaking Strength Test

A Breaking Strength Test was accomplished for each weathered sample using guidance provided in ASTM D5035-95, Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method) and U.S. Department of Transportation (1976) AC65-15A. The force needed to tear the material was recorded for each of the uncoated fabric and process samples at each weathering interval. The average data obtained for the weathered-uncoated fabric samples are contained in Table 23 and graphically displayed in Figure 12.

TABLE 23

BREAKING STRENGTH (LB.) -WEATHERED UNCOATED FABRIC DATA

QUV Hours	Cotton	Ceconite	Superflite	Stits
0	85	190	135	120
400	52	52	50	50
800	40	45	25	17
1200	25	15	20	15
1600	25	20	15	12
2000	27	15	12	10

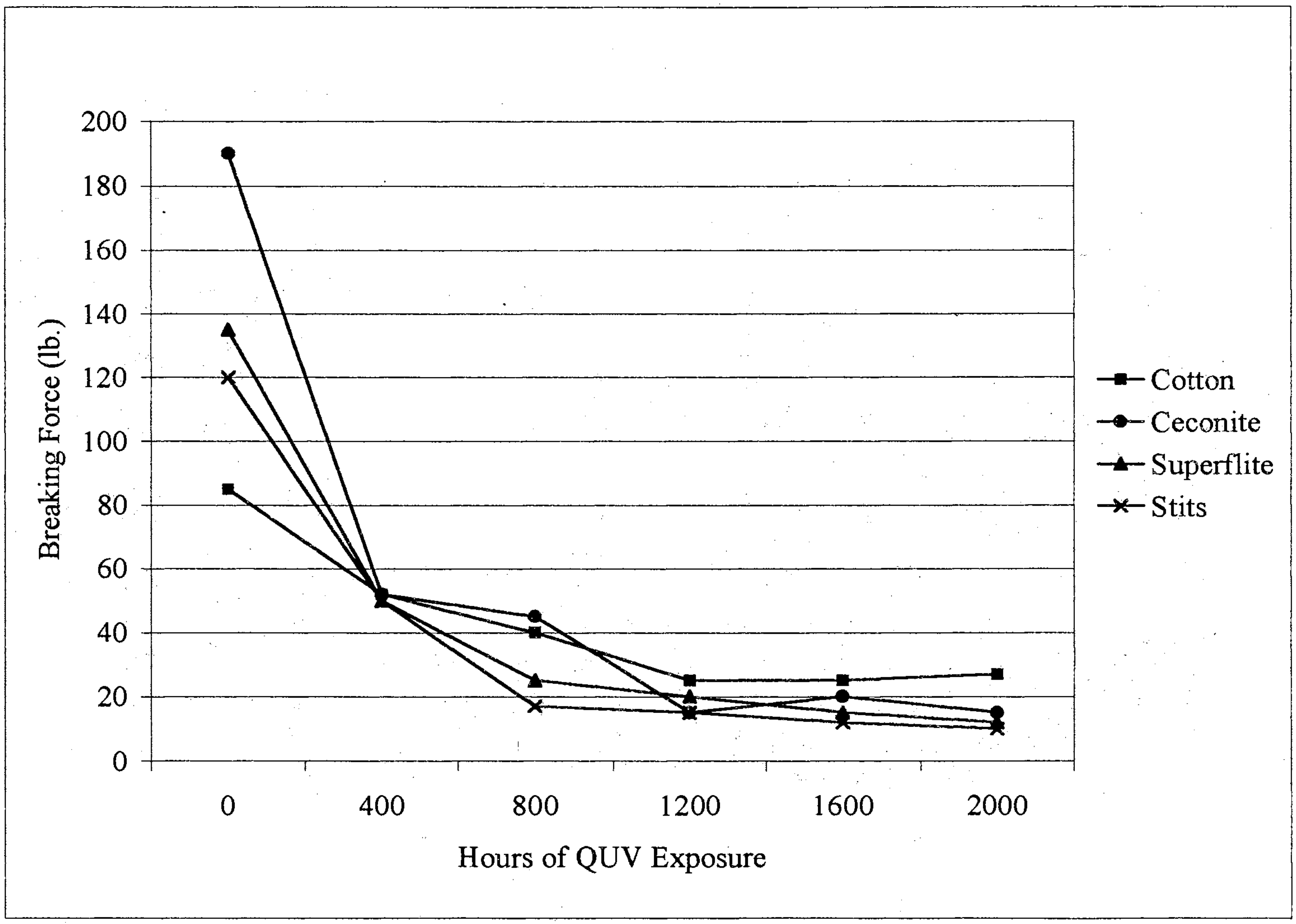

Figure 12. Breaking Strength (lb.) – Weathered-Uncoated Fabric Samples

Ceconite had the highest initial breaking strength at 190 lb., yet deteriorated very rapidly during the 0-400 hour interval of QUV weathering exposure. Beyond the 400-hour point all uncoated samples uniformly lost breaking strength.

To determine if there was a significant difference in breaking strength among the weathered-uncoated samples, Hypothesis 3 in Chapter I, the Analysis of Variance on the data of Table 23 was accomplished. The results of that analysis are summarized in Table 24 and indicate no significant difference in breaking strength among the uncoated organic cotton and synthetic polyester fabrics due to weathering.

TABLE 24

ANALYSIS OF VARIANCE – BREAKING STRENGTH TEST OF WEATHERED-UNCOATED FABRIC SAMPLES

<table>
<tr><th colspan="8">PROCESS COMPARISONS DUE TO WEATHERING</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-A</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>1,169.00</td><td>3</td><td>389.67</td><td rowspan="2">0.17</td><td rowspan="2">3.10</td><td rowspan="2">X</td><td rowspan="2"></td></tr>
<tr><td>Error</td><td>389.67</td><td>20</td><td>2,295.62</td></tr>
<tr><td>Hypothesis-A</td><td colspan="7">There is no significant difference in breaking strength among the uncoated fabric samples due to weathering.</td></tr>
<tr><th colspan="8">PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-B</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>40,504.83</td><td>5</td><td>6,576.50</td><td rowspan="2">22.17</td><td rowspan="2">2.77</td><td rowspan="2"></td><td rowspan="2">X</td></tr>
<tr><td>Error</td><td>55.96</td><td>24</td><td>2.33</td></tr>
<tr><td>Hypothesis-B</td><td colspan="7">There is no significant difference in breaking strength among the uncoated fabric samples for any given exposure time.</td></tr>
</table>

Thus, Hypothesis 3 in Chapter I is rejected since Hypothesis-A of Table 24 is its null hypothesis, H_0. Because Hypothesis-A of Table 24 is accepted, Tukey's Honest Significant Difference Test is not applied to the table data. However, an Analysis of Variance on process comparisons for any given exposure time of the uncoated fabric samples, Hypothesis-B of Table 24, indicates there was significant difference in breaking strength among the uncoated fabric for any given exposure time.

Because Hypothesis-B of Table 24 was rejected, Tukey's Honest Significant Difference Test was applied to the data. The results of that analysis are illustrated in Table 25 and provide insight into the rejection rationale. First, there is a significant difference in the average breaking strength between the initial test and at each of the remaining five QUV exposure time intervals. Thus, most weathering weakening occurred during the first 400 hours of exposure. Second, there is no significant difference between the remaining time pairs indicating that weather degradation had stabilized.

The average data obtained for the weathered process samples are contained in Table 26 and graphically displayed in Figure 13. The shape of the graph indicates a general decrease in breaking strength for all the weathered processes. Superflite had the most rapid deterioration, starting out at 232 lb. and decreasing to 107 lb. at 2000 hours of weathering exposure. The 400-hour to 800-hour period of exposure resulted in an 85-lb. loss in strength for Superflite. The most consistent process sample was Stits with the highest average mean of 170 lb., starting out at 175 lb. and then decreasing to 155 lb.

TABLE 25

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – BREAKING STRENGTH TEST- UNCOATED FABRIC COMPARISONS FOR ANY GIVEN EXPOSURE TIME

	QUV Hours 0	QUV Hours 400	QUV Hours 800	QUV Hours 1200	QUV Hours 1600	QUV Hours 2000	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
μ_{Hours}	132.5	51.0	31.7	18.7	18.0	16.0			Accept	Reject
COMPARISONS	μ_1	μ_2					81.5	38.4		X
	μ_1		μ_2				100.8	38.4		X
	μ_1			μ_2			113.8	38.4		X
	μ_1				μ_2		114.5	38.4		X
	μ_1					μ_2	116.5	38.4		X
		μ_1	μ_2				19.3	38.4	X	
		μ_1		μ_2			32.3	38.4	X	
		μ_1			μ_2		33.0	38.4	X	
		μ_1				μ_2	35.0	38.4	X	
			μ_1	μ_2			13.0	38.4	X	
			μ_1		μ_2		13.7	38.4	X	
			μ_1			μ_2	15.7	38.4	X	
				μ_1	μ_2		0.7	38.4	X	
				μ_1		μ_2	2.7	38.4	X	
					μ_1	μ_2	2.0	38.4	X	

H_0: There is no significant difference in breaking strength among the processes between each exposure Time.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject
$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

TABLE 26

BREAKING STRENGTH (LB.) – WEATHERED PROCESS DATA

QUV Hours	Cotton Randolph	Ceconite Randolph	Air-Tech	Superflite	Stits
0	145	150	116	232	175
400	110	135	105	210	174
800	95	140	100	125	185
1200	90	135	105	110	182
1600	100	137	105	112	150
2000	120	125	107	107	155

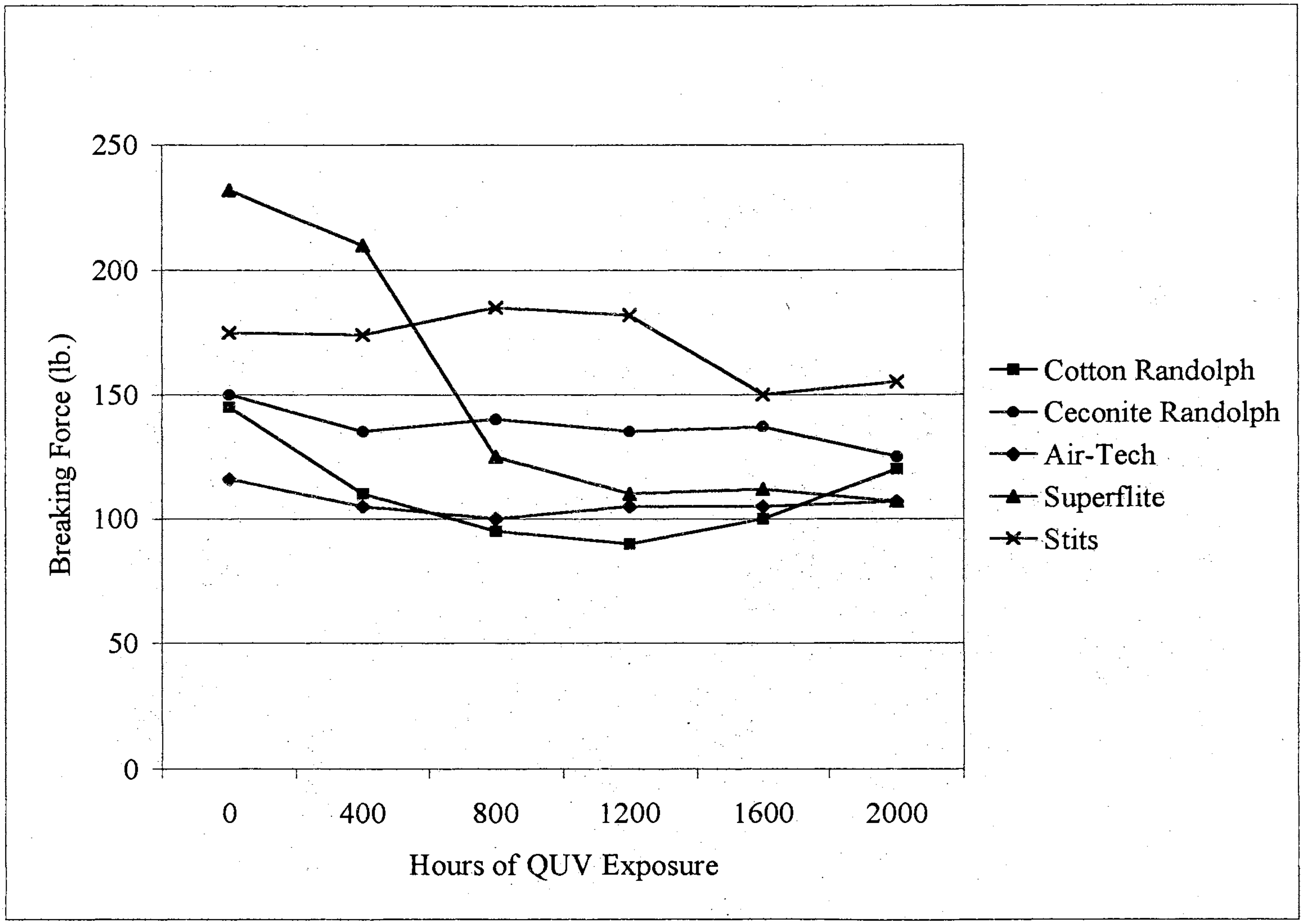

Figure 13. Breaking Strength (lb.) – Weathered Process Samples

To determine the extent of the differences among all the processes, an Analysis of Variance on the data of Table 26 was accomplished to determine (1) if there was a significant difference in the breaking force among the weathered process samples due to weather degradation, Hypothesis 4 in Chapter I, and (2) if there was a significant difference in the breaking force among the process samples for any given exposure time, Hypothesis 5 in Chapter I. The results of that analysis are summarized in Table 27 and indicate that (1) Hypothesis-A is rejected, while (2) Hypothesis-B is accepted. Thus, Hypothesis 4 in Chapter I is accepted, since Hypothesis-A of Table 27 is its null hypothesis, H_0, and Hypothesis 5 in Chapter I is rejected, since Hypothesis-B of Table 27 is its null hypothesis, H_0.

TABLE 27

ANALYSIS OF VARIANCE – BREAKING STRENGTH TEST OF WEATHERED PROCESS SAMPLES

<table>
<tr><td colspan="8">PROCESS COMPARISONS DUE TO WEATHERING</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Sum of Squares</td><td rowspan="2">Degrees of Freedom</td><td rowspan="2">Mean Square</td><td rowspan="2">F Ratio</td><td rowspan="2">$F_{0.05}$ Table</td><td colspan="2">Hypothesis-A</td></tr>
<tr><td>Accept</td><td>Reject</td></tr>
<tr><td>Between</td><td>17,351.87</td><td>4</td><td>4,337.97</td><td rowspan="2">5.59</td><td rowspan="2">2.76</td><td rowspan="2"></td><td rowspan="2">X</td></tr>
<tr><td>Error</td><td>19,393.50</td><td>25</td><td>775.74</td></tr>
<tr><td>Hypothesis-A</td><td colspan="7">There is no significant difference in breaking strength among the process samples due to weathering.</td></tr>
<tr><td colspan="8">PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Sum of Squares</td><td rowspan="2">Degrees of Freedom</td><td rowspan="2">Mean Square</td><td rowspan="2">F Ratio</td><td rowspan="2">$F_{0.05}$ Table</td><td colspan="2">Hypothesis-B</td></tr>
<tr><td>Accept</td><td>Reject</td></tr>
<tr><td>Between</td><td>7,274.57</td><td>5</td><td>1,454.91</td><td rowspan="2">1.18</td><td rowspan="2">2.62</td><td rowspan="2">X</td><td rowspan="2"></td></tr>
<tr><td>Error</td><td>29,470.80</td><td>24</td><td>1,227.95</td></tr>
<tr><td>Hypothesis-B</td><td colspan="7">There is no significant difference in breaking strength among the process samples for any given exposure time.</td></tr>
</table>

Because Hypothesis-A of Table 27 is rejected, Tukey's Honest Significant Difference Test is applied to the data. The results of that analysis are illustrated in Table 28 and show that the rejection of Hypothesis-A of Table 27 is a result of the higher than average breaking strength of Stits over Cotton with Randolph dope and Air-Tech processes. Additionally, since there was no significant difference between cotton and polyester fabric processes in strength degradation, the type of coating material was a significant factor in strength retention throughout the weathering cycle.

TABLE 28

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – BREAKING STRENGTH TEST PROCESS COMPARISONS DUE TO WEATHERING

	Cotton Randolph	Ceconite Randolph	Air Tech	Superflite	Stits	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
Means (μ)	110.0	137.0	106.3	149.3	170.2			Accept	Reject
COMPARISONS	μ_1	μ_2				27.0	47.3	X	
	μ_1		μ_2			3.7	47.3	X	
	μ_1			μ_2		39.3	47.3	X	
	μ_1				μ_2	60.2	47.3		X
		μ_1	μ_2			30.7	47.3	X	
		μ_1		μ_2		12.3	47.3	X	
		μ_1			μ_2	33.2	47.3	X	
			μ_1	μ_2		43.0	47.3	X	
			μ_1		μ_2	63.9	47.3		X
				μ_1	μ_2	20.9	47.3	X	

H_0: There is no significant difference in breaking strength between each process pair due to weathering.

Hypothesis Test: $|\mu_1-\mu_2| > CD$ - Reject
$|\mu_1-\mu_2| < CD$ - Accept

Thermal Stress Test

A Thermal Stress Test was accomplished for each weathered process sample using guidance provided in ASTM E162-94, Standard Test Method for Surface Flammability of material using a Radiant Heat Energy Source. The test used in this research provides a means to determine the thermal stress resistance of a coated sample by recording the elapsed time to burn through the material under a 0.5 lb. tension when exposed to 1,250°F ± 50° at the base fabric surface. For each of the weathered process samples, the time to ignite and burn through a 2" x 1" section of material was analyzed to determine the differences among the process samples. The average data obtained from the Thermal Stress Test is contained in Table 29 and graphically displayed in Figure 14 for all weathered process samples.

TABLE 29

THERMAL STRESS TIME-TO-BREAK (SEC.)
WEATHERED PROCESS DATA

QUV Hours	Cotton Randolph	Ceconite Randolph	Air-Tech	Superflite	Stits
0	12.29	5.28	12.73	14.46	14.27
400	15.48	6.53	14.12	10.98	12.74
800	11.84	4.80	13.50	7.55	7.54
1200	12.53	5.47	9.90	9.00	6.28
1600	10.49	6.41	10.93	8.59	5.90
2000	11.60	5.71	12.56	11.83	7.66

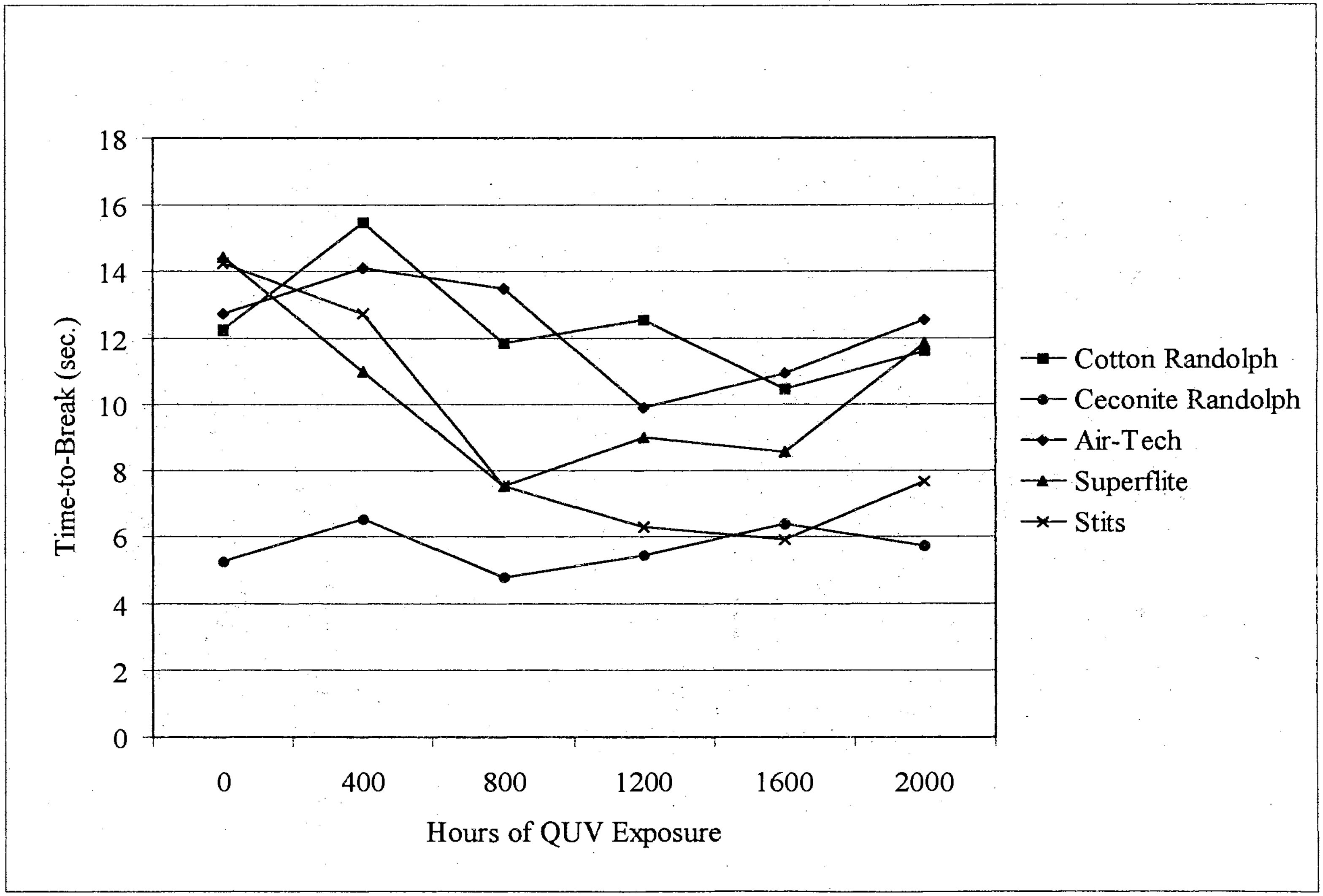

Figure 14. Thermal Stress Time-to-Break (sec.) – Weathered Process Samples

The data curves of Figure 14 indicate a general reduction in thermal stress resistance throughout the 2000 hours of QUV testing. The Ceconite with Randolph dope had the fastest breaking time of 5.7 seconds while Cotton with Randolph dope had the slowest breaking time of 15.48 seconds.

To determine if there was a significant difference in breaking times among the process samples due to weather degradation, Hypothesis 6 in Chapter I, an Analysis of Variance on the data of Table 29 was accomplished. The results of that analysis are summarized in Table 30 and indicate a significant difference among the processes due to weathering.

TABLE 30

ANALYSIS OF VARIANCE – THERMAL STRESS TEST OF WEATHERED PROCESS SAMPLES

PROCESS COMPARISONS DUE TO WEATHERING							
	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.05}$ Table	Hypothesis-A	
						Accept	Reject
Between	182.33	4	45.58	9.20	2.76		X
Error	123.88	25	4.96				
Hypothesis-A	There is no significant difference in the thermal stress resistance among the process samples due to weathering.						
PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME							
	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.05}$ Table	Hypothesis-B	
						Accept	Reject
Between	61.41	5	12.28	1.20	2.62	X	
Error	244.80	24	10.20				
Hypothesis-B	There is no significant difference in the thermal stress resistance among the process samples for any given exposure time.						

Thus, Hypothesis 6 in Chapter I is accepted, since the Hypothesis-A of Table 29 is its null hypothesis, H_0. The process comparisons for any given exposure time, Hypothesis-B, results in acceptance of the null hypothesis, H_0, which states that there is no significant difference in resistance to thermal stress resistance among the process for any given exposure time.

Because Hypothesis-A of Table 30 is rejected, Tukey's Honest Significant Difference Test was applied to the data. The results of that analysis are illustrated in Table 31.

TABLE 31

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – THERMAL STRESS TEST - PROCESS COMPARISONS DUE TO WEATHERING

	Cotton Randolph	Ceconite Randolph	Air Tech	Superflite	Stits	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
Means (μ)	12.37	5.70	12.29	10.40	9.07			Accept	Reject
COMPARISONS	μ_1	μ_2				6.67	3.78		X
	μ_1		μ_2			0.08	3.78	X	
	μ_1			μ_2		1.97	3.78	X	
	μ_1				μ_2	3.30	3.78	X	
		μ_1	μ_2			6.59	3.78		X
		μ_1		μ_2		4.70	3.78		X
		μ_1			μ_2	3.37	3.78	X	
			μ_1	μ_2		1.89	3.78	X	
			μ_1		μ_2	3.22	3.78	X	
				μ_1	μ_2	1.33	3.78	X	

H_0: There is no significant difference in the thermal stress resistance between each process pair due to weathering.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject
$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

The results of Tukey's Honest Significant Difference Test from Table 31 indicate two main reasons for the rejection of Hypothesis-A of Table 30. First, Ceconite with Randolph dope had the fastest average breaking time compared to those of the other process coatings. Second, since there was no significant difference between cotton and polyester fabric processes, the type of coating material applied to the fabric was a factor in the loss of thermal stress resistance at all weathering intervals.

Additionally, during the Thermal Stress Test, the Ceconite with Randolph dope samples were very volatile, bursting into flame after ignition occurred. Furthermore, the weathered Superflite process samples emitted thick acrid smoke when ignition and burning began.

CHAPTER V

SUMMARY, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to examine and compare the design and performance properties of aircraft fabric covering using the Grade-A cotton with Randolph dope, Ceconite with Randolph dope, Cooper Superflite II, Air-Tech Coatings, and Stits Poly-Fiber processes. The design properties studied were characteristics of the uncoated fabric and nonweathered-coated material. The performance properties investigated were coating surface changes, strength degradation and response to heat and flame throughout accelerated weathering of the material.

This study had two broad objectives in support of the purpose of the study. The first objective examined the design properties of the five processes to compare their initial elongation, breaking strength, thickness and weight characteristics. The second objective investigated progressive weathering effects on the five processes and their performance in gloss retention, coating yellowing, low temperature flexibility, breaking strength, and thermal stress resistance at each weathering interval.

The hypotheses were written to answer questions about how a selected fabric-covering method performs over its intended life and in a variety of functional areas. This information is vital to assist aircraft manufacturers and maintenance personnel in choosing the fabric and covering method that is not only cost effective in terms of labor and material, but also provides the least degradation over the service life of the aircraft.

Discussion of Research Findings

Design Properties

The investigation of the design properties pointed out that bare Ceconite 101 fabric stretched almost 27% more than the average, yet had a breaking strength of almost 60 lb. more than the average value for all the samples. This increase in elongation and strength can be attributed to its greater thickness, 0.0030", over that of the other polyester fabrics. The measured thickness of the samples did not change at each weathering exposure time.

A comparison of the weight in pounds per square foot (lb/ft^2) of the process samples showed that the Air-Tech and Superflite processes add about 20% and 40% respectively, more weight per square foot than the process average. This increase in weight can be attributed to the application of the thick consistency and high solids polyurethane finish used as part of these processes. For a typical small airplane such as the Piper J-3 Cub, a 40% increase in aircraft fabric weight reduces the useful load approximately 5%.

Performance Properties

The investigation of the gloss retention characteristics of the process samples showed that Superflite and Air-Tech had excellent gloss retention over the complete weathering cycle. This is a result of the polyurethane topcoats, which are extremely durable. Although Stits is polyurethane based, it does not contain high solids that contribute to long term durability like those contained in the Air-Tech and Superflite processes. The gloss retention ability of Randolph dope was not affected by Cotton or Ceconite base fabrics and rapidly lost its gloss after 400 hours of QUV exposure.

All of the processes except Ceconite with Randolph dope were stable in yellowing degradation. Ceconite with Randolph Dope yellowed at a very high rate after 800 hours of QUV weathering and ended with the highest yellowing index. It appears that Ceconite with Randolph dope is a poor combination for weather related degradation factors. Stits was the most stable with a slight increase in yellowing between 400 and 800 hours of QUV weathering. The vinyl coatings and top coat combinations appear to be very effective in reducing yellowing degradation.

The Breaking Strength Test is the first of the two most important tests conducted on the process samples because integrity, stability, and safety of the fabric covering the airframe are extremely important. The rapid strength deterioration of Superflite over the 2000 hours of QUV exposure indicates a problem with adequate UV protection, because that is the single biggest factor in polyester deterioration. Although the other process lost some strength over the weathering cycle, they exhibited no inconsistent or unusual behavior.

The Thermal Stress Test is the second most important test conducted on the process samples due to safety of flight issues. Clearly, all processes lost their thermal stress resistance over the weathering cycle. Ceconite with Randolph dope was a volatile combination, which accounts for its lower time-to-break data curve. Air-Tech and Stits prepared samples resisted sustained burning after ignition, even though the Stits process indicated a decrease in thermal resistance over the QUV weathering cycle. Superflite had improved thermal stress performance towards the end of the weathering cycle, but its burn characteristics included emission of thick black acrid smoke, which was significantly different behavior than the other samples.

Discussion of Hypotheses

The hypotheses were chosen to test the characteristics of the processes that are of importance to the general aviation community. Gloss and yellowing are important to those wanting show quality aircraft, while breaking force and thermal stress resistance are important to those wanting longevity and safety. Table 32 summarizes Chapter I hypotheses and their subsequent acceptance or rejection based upon the ANOVA testing method.

The rejection of Hypothesis 3 and Hypothesis 5 of Table 32 are surprising. Ultraviolet light has always been considered more damaging to polyester type fabrics than the Grade-A cotton. However, the data and hypotheses suggest that weathering effects cause similar strength degradation for both types of fabrics. However, Grade-A cotton is subject to mildew, fungus, and other degradation that does not factor into the breaking strength deterioration inherent in this type of accelerated QUV weathering.

TABLE 32

SUMMARY OF CHAPTER I HYPOTHESES STATEMENTS

Chapter I Hypotheses Statements			
Number	Statement	Accept	Reject
1	There is a significant difference in the gloss retention characteristics among the process samples due to weather degradation.	X	
2	There is a significant difference in yellowing among the process samples due to weather degradation.	X	
3	There is a significant difference in the breaking force among the uncoated organic cotton and synthetic polyester fabrics due to weathering.		X
4	There is a significant difference in the breaking force among the process samples due to weathering.	X	
5	There is a significant difference in the breaking force among the process samples for any give exposure time.		X
6	There is a significant difference in the thermal stress resistance among the process samples due to weathering.	X	

The rejection of Hypothesis 5 indicates that there is no significant difference in the breaking force among the process samples for any give exposure time. In other words, the average degradation among the samples between weathering times was not unique or out of statistical limits. Thus, when considering the strength degradation due to weathering, a complete life cycle analysis must be considered so that small between-weathering-time changes are considered in the total weathering degradation.

Conclusions

The design properties tested indicated that all of the uncoated fabric samples met the maximum elongation percentage and minimum initial breaking strength. Investigation of the thickness and weight of the process samples show that there are significant differences among the processed samples for these design properties.

The performance properties tested on weathered process samples were gloss retention, yellowing degradation, low temperature bending, breaking strength, and thermal stress resistance. Analysis of Variance statistical hypothesis testing was accomplished on that data and showed that there were significant differences among the process samples for these performance properties.

Additional hypothesis testing was accomplished on process comparisons to determine differences for any given exposure time. Their results provided additional insight into the differing characteristics of the process samples. Finally, there are other significant differences that can be inferred about the processes from the data given, which will be covered in the next section.

Implications

It is apparent that there are significant differences in design and performance properties among the five FAA approved covering processes studied in this research effort. Thus, choosing the best method to use is a difficult decision for manufacturers and mechanics alike. This decision must be made on an individual basis, factoring in aircraft operating environments, type of service, and other economic factors.

However, this researcher believes the important design and performance characteristics investigated in this study can be combined to give an overall subjective performance score that ranks the processes among themselves. Once performance scoring is accomplished, statistical analysis of that data can provide insight into the differences among the processes.

First, the design and performance characteristics of weight, gloss, yellowing, low temperature, breaking strength, and thermal stress resistance may be sorted in terms of desired "high" or "low" values of measurement. Table 33 provides scoring for those design and performance qualities of importance to consider in selecting a coating process.

TABLE 33

HIGH/LOW SORTING OF DESIGN AND PERFORMANCE DATA

Design or Performance Characteristic	Desired Value	
	High	Low
Weight of Overall Fabric		X
Yellowing of Coated Surface		X
Thermal Stress Resistance of Coated Fabric	X	
Breaking Force (Strength of Fabric)	X	
Gloss of Coated Surface	X	
Cold Weather Performance	X	

Next, using the criteria contained in Table 33, a Performance Index (PI) equation can be written of the form,

$$PI = \frac{\text{(Breaking Force)(Gloss Index)(Cold Test)(Thermal Stress Resistance)}}{\text{(Weight)(Yellowing Index)(Scaling Factor)}} \tag{14}$$

where,

Weight = Values from Table 15

Gloss Index = Values from Table 16

Yellowing Index = Values from Table 19

Low Temperature Bend Test = Values from Table 22, (1=Pass, 0.7=Fail)

Breaking Force = Values from Table 26

Thermal Stress Resistance = Values from Table 29

Scaling Factor = Set at 1000 to provide better resolution of PI values

The numerator and denominator arrangements of Equation 14 were selected to maximize the value of the Performance Index. Thus, low denominator values, when inverted, become higher multipliers for the numerator values. The overall Performance Index is calculated for all processes using Equation 14 and summarized in Table 34.

TABLE 34

PERFORMANCE INDEX DATA

QUV Hours	Cotton Randolph	Ceconite Randolph	Air-Tech	Superflite	Stits
0	97	43	82	242	258
400	64	30	58	153	160
800	19	11	57	43	112
1200	13	6	35	42	74
1600	18	10	41	39	42
2000	12	5	46	52	56

The data within Table 34 does not represent any particular units, that is, feet per second or pounds, just an overall scaled magnitude from the individual table values that were inserted into Equation 14.

The data of Table 34 can be graphically represented as shown in Figure 15. The process sample data curves contained in Figure 15 indicate that Stits has the best overall performance rating throughout the QUV weathering cycle. Superflite performance dropped radically during the first 800 hours of testing, yet stabilized during the remaining 1200 hours of weathering. Between 1600 and 2000 hours of QUV weathering exposure, Stits, Superflite, and Air-Tech processes performed similarly. Air-Tech had the most stable performance degradation of the top three finishers starting out with a performance index of 82 and finishing at 46, as compared to Superflite starting with 242 and finishing at 52. Ceconite with Randolph dope was the poorest performer followed by Grade-A cotton with Randolph dope. Although both of these processes performed similarly, their curves were significantly lower than those for Stits, Superflite, and Air-Tech.

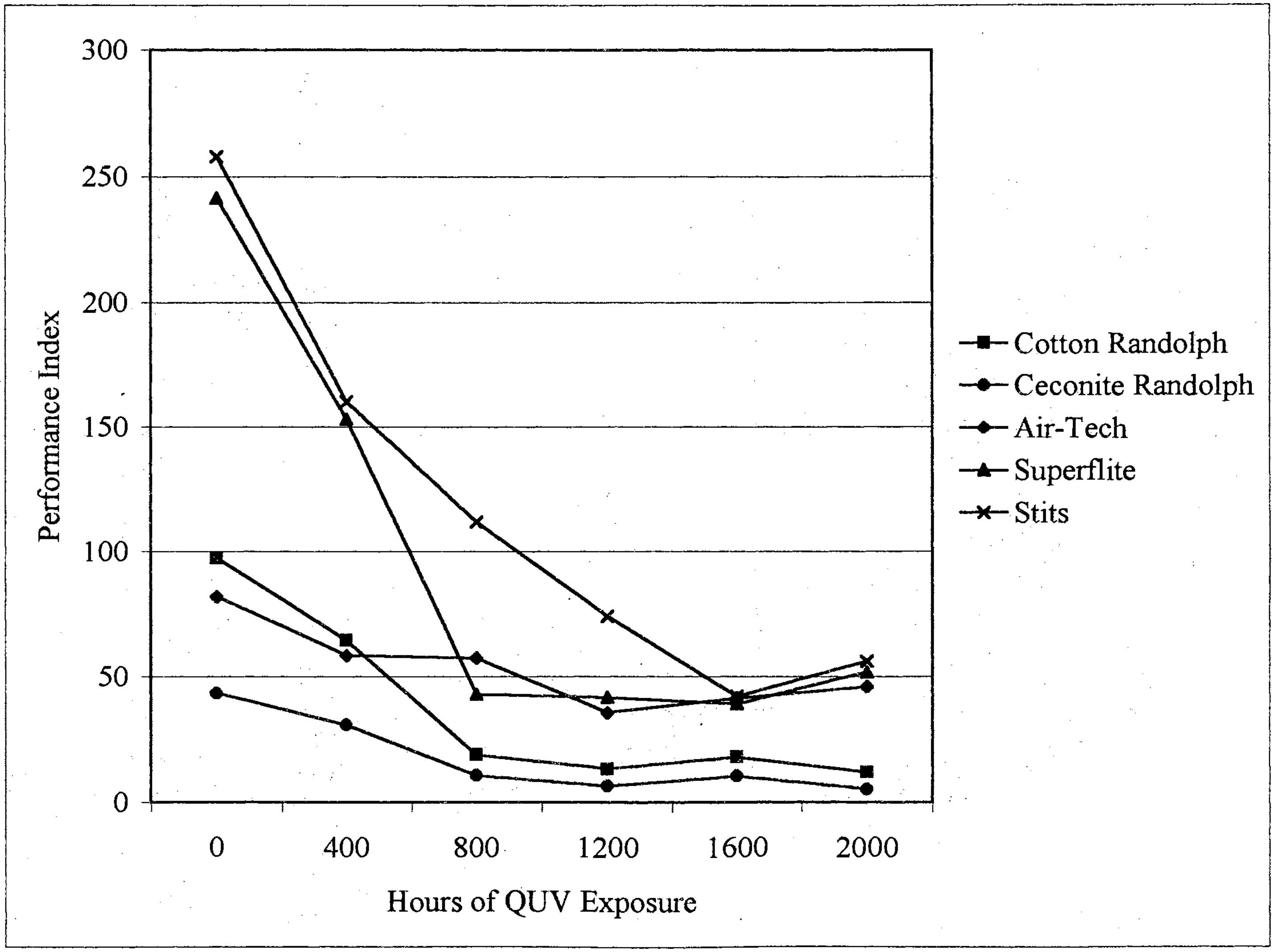

Figure 15. Performance Index for Processes

In order to determine if there is a significant difference in the performance index among the process samples due to weather degradation, the Analysis of Variance on the data of Table 34 was accomplished, Table 35.

TABLE 35

ANALYSIS OF VARIANCE – PERFORMANCE INDEX OF WEATHERED PROCESS SAMPLES

<table>
<tr><th colspan="8">PROCESS COMPARISONS DUE TO WEATHERING</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-A</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>40,680</td><td>4</td><td>10,170</td><td rowspan="2">3.29</td><td rowspan="2">2.76</td><td rowspan="2"></td><td rowspan="2">X</td></tr>
<tr><td>Error</td><td>77,228</td><td>25</td><td>3,089</td></tr>
<tr><td>Hypothesis-A</td><td colspan="7">There is no significant difference in performance among the process samples due to weathering.</td></tr>
<tr><th colspan="8">PROCESS COMPARISIONS FOR ANY GIVEN EXPOSURE TIME</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Sum of Squares</th><th rowspan="2">Degrees of Freedom</th><th rowspan="2">Mean Square</th><th rowspan="2">F Ratio</th><th rowspan="2">$F_{0.05}$ Table</th><th colspan="2">Hypothesis-B</th></tr>
<tr><th>Accept</th><th>Reject</th></tr>
<tr><td>Between</td><td>52,463</td><td>5</td><td>10,493</td><td rowspan="2">3.85</td><td rowspan="2">2.62</td><td rowspan="2"></td><td rowspan="2">X</td></tr>
<tr><td>Error</td><td>65,445</td><td>24</td><td>2,727</td></tr>
<tr><td>Hypothesis-B</td><td colspan="7">There is no significant difference in performance among the process samples for any given exposure time.</td></tr>
</table>

The results of Table 35 analysis indicate that both Hypothesis-A and Hypothesis-B are rejected at a chosen significance level of 0.05. Thus, there is a significant difference among the processes in overall performance throughout the weathering cycle.

Because Hypothesis-A of Table 35 is rejected, Tukey's Honest Significant Difference Test is applied to the data. The results of that analysis are illustrated in Table 36.

TABLE 36

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – PERFORMANCE INDEX PROCESS COMPARISONS DUE TO WEATHERING

	Cotton Randolph	Ceconite Randolph	Air Tech	Superflite	Stits	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
Means (μ)	37.17	17.50	53.17	95.17	117.00			Accept	Reject
COMPARISONS	μ_1	μ_2				19.67	94.39	X	
	μ_1		μ_2			16.00	94.39	X	
	μ_1			μ_2		58.00	94.39	X	
	μ_1				μ_2	79.83	94.39	X	
		μ_1	μ_2			35.67	94.39	X	
		μ_1		μ_2		77.67	94.39	X	
		μ_1			μ_2	99.50	94.39		X
			μ_1	μ_2		42.00	94.39	X	
			μ_1		μ_2	63.83	94.39	X	
				μ_1	μ_2	21.83	94.39	X	

H_0: There is no significant difference in performance retention between each process pair due to weathering.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject
$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

Analysis of data in Table 36 shows that the Stits process has a significantly higher performance index than Ceconite with Randolph dope, which accounts for the Table 35 hypothesis rejection. Borderline hypothesis acceptance for mean differences between

Stits and Grade-A cotton with Randolph dope indicates similarly higher performance for the Stits process.

Application of Tukey's Honest Significant Difference Test to Hypothesis-B of Table 35 is shown in Table 37.

TABLE 37

TUKEY'S HONEST SIGNIFICANT DIFFERENCE TEST – PERFORMANCE INDEX PROCESS COMPARISONS FOR ANY GIVEN EXPOSURE TIME

	QUV Hours 0	QUV Hours 400	QUV Hours 800	QUV Hours 1200	QUV Hours 1600	QUV Hours 2000	$\lvert\mu_1-\mu_2\rvert$	Critical Difference (CD)	Null Hypothesis (H_0)	
μ_{Hours}	144.4	93.0	48.4	34.0	30.0	34.2			Accept	Reject
COMPARISONS	μ_1	μ_2					51.4	102.0	X	
	μ_1		μ_2				96.0	102.0	X	
	μ_1			μ_2			110.4	102.0		X
	μ_1				μ_2		114.4	102.0		X
	μ_1					μ_2	110.2	102.0		X
		μ_1	μ_2				44.6	102.0	X	
		μ_1		μ_2			59.0	102.0	X	
		μ_1			μ_2		63.0	102.0	X	
		μ_1				μ_2	58.8	102.0	X	
			μ_1	μ_2			14.4	102.0	X	
			μ_1		μ_2		18.4	102.0	X	
			μ_1			μ_2	14.2	102.0	X	
				μ_1	μ_2		4.0	102.0	X	
				μ_1		μ_2	0.2	102.0	X	
					μ_1	μ_2	4.2	102.0	X	

H_0: There is no significant difference in performance between each process pair for any given exposure time.

Hypothesis Test: $\lvert\mu_1-\mu_2\rvert > CD$ - Reject
$\lvert\mu_1-\mu_2\rvert < CD$ - Accept

The data of Table 37 indicates significant performance differences between all weathering intervals after the weathering process began. Additionally, the data suggests that performance levels begin to stabilize after 1200 hours of QUV weathering. In fact, there was little difference in the mean values at the 1200-hour and 2000-hour exposure times.

Recommendations

Although this study was replete with meaningful and worthwhile information, it only scratches the surface of research available in this field of study. Thus, during the course of the research, additional areas of study have been observed and are suggested as subjects for future work. Continued research will enhance the understanding of various aircraft fabric-covering processes and lead to safer operation of general aviation aircraft.

First, vibration must be considered in the overall weathering effect. Currently, the QUV tester does not have the capability to introduce vibration into the weathering cycle. Modification to the QUV chamber to incorporate vibration frequencies associated with those of small aircraft flight conditions will introduce another real-world condition to the testing. The hard polyurethane finishes may deteriorate more rapidly under these conditions.

Second, the static electricity generation and dissipation characteristics of each material must be evaluated. Not only is this important to static free radio reception, but also for safety in terms of a potential fire hazard.

Finally, a better correlation between accelerated weathering hours and actual outdoor weathering exposure will establish a solid baseline for evaluating materials over the five to ten year ownership cycle of general aviation aircraft.

Concluding Comment

It has been the intent of this research effort to provide baseline information to the aviation community on the weathering characteristics of various aircraft fabric-covering processes. This study has investigated only a few of the properties that are of interest, but having this solid and unbiased information will ensure sound decisions are made regarding the selection of a covering method that will offer the best performance over the lifetime of the aircraft.

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