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Rapid Site Preparation for Turbojet VTOL Aircraft

TECHNICAL DOCUMENTARY REPORT NO. APL-TDR 64-125
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AIR FORCE AERO PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

PROJECT NO. 8174, TASK NO. 817401

(Prepared under Contract No. AF 33(615)-1092 by Ling-Temco-Vought, Inc., LTV Vought Aeronautics Division, Dallas, Texas 75222. Authors: J. E. Butler and G. F. Thomas)

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FOREWORD

This report was prepared by LTV Vought Aeronautics Division, under USAF Contract No. AF 33(615)-1092. This contract was initiated under Project No. 8174, "Limited War Support Techniques," Task No. 817401, "Rapid Site Preparation VTOL/STOL Aircraft." This work was administered under the direction of the Support Techniques Branch, Air Force Aero Propulsion Laboratory, Research and Technology Division, Air Force Systems Command, Wright Patterson Air Force Base, Ohio. Mr. A. Vasiloff was technical monitor.

This report covers work conducted from 1 October 1963 through 31 August 1964.

Mr. J. E. Butler was the LTV Vought Aeronautics Principal Investigator. Mr. G. F. Thomas and Mr. H. J. Poskey were engineers in charge of material development. Suggestions by Mr. R. S. Rembert, engineering materials specialist, are also acknowledged.

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This report is not released to OTS due to patent application revealed in this report.

ABSTRACT

A sprayable, rapid-curing, light-weight, low-cost material system for use as a remote landing and take-off site for turbojet VTOL aircraft was developed. The material system was composed of a chlorinated polyester resin system modified with temperature resistant additives and fiber glass reinforcement. The capabilities of the material system were demonstrated by testing in the direct exhaust of an afterburning J85-GE-5 turbojet engine in the Research and Technology Division jet test facility and by an operational field site used for repeated take-off and landings of an X-14A jet VTOL aircraft. The material system withstood temperatures up to 3000°F for short time periods. It is believed that the basic VTOL landing site area exposed to the severe temperatures and velocities of a jet engine exhaust can be fabricated using a maximum of 2.5 lbs./ft.^{2}.

This technical documentary report has been reviewed and is approved.

ROSS J. GAFVERT, Chief
Support Techniques Branch
Technical Support Division
AF Aero Propulsion Laboratory

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SECTION 1

INTRODUCTION

The concept of utilizing jet or turbo-prop vertical take-off and landing (VTOL) aircraft in remote areas for frontline support has generated a requirement for rapid site preparation. A rapid site capability will permit VTOL aircraft to utilize more fully their short landing and take-off characteristics. The rapid preparation of a VTOL jet aircraft landing site presents a formidable problem. If the preparation is to be done in a matter of hours with a small number of troops or from an aircraft, many problems such as logistics, material weight, and dispensing methods are involved.

Other problems arise that can seriously restrict the full utilization of the aircraft when the propulsion concept for a VTOL type aircraft is designed for the exhaust to be directed perpendicular to the ground site rather than being deflected in some manner. The excessive clouds of dust, debris, and flying objects formed during VTOL take-offs and landing create the following problems: obstruction of pilots' vision, damage to aircraft structure, damage to propulsion system by ingestion of foreign objects, and aircraft position giveaway to the enemy. The problem is further heightened if afterburner conditions are used.

The operation of the VTOL aircraft in remote and frontline areas establishes the requirement that the site preparation be economical, be rapidly accomplished without aid of heavy equipment, and be achieved under a variety of soil and weather conditions. Site hardening techniques must be developed to satisfy these requirements and alleviate the above mentioned problem areas. For example, many gallons of materials would be necessary to prepare a site of 2,000 square feet, approximately 50 foot diameter circle only a few inches thick. A one-inch thick coating of a 70 lb./cu. ft. material would require almost six tons of material for such a site. This logistics problem must be resolved, as this example weight could not be carried by the aircraft, and there would be a serious transportation problem of getting such a load to a remote site via jeep type vehicle.

In order to properly utilize the VTOL aircraft's remote site capability, considerable attention must be given to the problem of designing an economical and simple site hardening materials system capable of operating in various climatic extremes while also being capable of surviving the VTOL exhaust temperature and blast effects.

The many problems involved in operating VTOL aircraft over unprepared terrain have stimulated extensive investigations by government agencies and industry into methods to solve or alleviate the problems. Much of this effort has been concerned with the suppression of downwash effects resulting from rotor and turbo-prop type aircraft. Investigations of jet type VTOL vehicles have generally been limited to non-afterburning operations. For example, the LTV

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Vought Aeronautics Division initiated studies of VTOL downwash suppression during 1960. These studies, which are described in reference (1) were performed with a small, high-velocity, low-temperature jet. Investigations centered upon sprayed resins and means for their reinforcement.

The development of a vertically mounted J-85 jet engine facility at the Research and Technology Division of the Air Force represents a major step toward the systematic investigation of possible solutions to the problems of high-temperature high-velocity downwash blast. This facility which includes afterburning engine operation is capable of simulating the complete cycle of take-off and landing of lifting jet VTOL vehicles. The initial investigations performed with this facility by Air Force Aero-Propulsion Laboratory personnel are reported in reference (2). The present program represents an extension of these efforts.

The original objectives of this program were to evaluate material systems, develop material application techniques, and define the parameters pertinent to the rapid preparation of VTOL landing sites. More specifically, the detail objectives were to:

- Conduct an evaluation of different chemicals, plastics, and various materials for usefulness as a rapid site preparation composition.

- Evaluate performance of various potential hardening chemicals or other agents as tested at RTD VTOL research facility.

- Correlate theoretical equations or calculations and experimental results of the testing program under simulated VTOL conditions at RTD facility.

- Define the various parameters of rapid site preparation and any design trade-offs needed for combining these parameters.

- Define and fabricate, if possible, various dispersion techniques and experimental equipment necessary for rapid site preparation of compositions found usable in the testing program.

As the investigations proceeded, the results appeared sufficiently promising to warrant the addition of a sixth objective to the program, i.e.,

- Conduct full-scale fabrication experiments in the field at NASA, Ames, and allow the X-14A VTOL aircraft to operate from these sites.

An industrial survey was conducted to determine all potentially suitable candidate materials. This survey was followed by procurement of the selected materials which then underwent screening tests in the LTV Vought Aeronautics Division laboratories. Material systems using the most promising materials were developed and evaluated. The performance of material systems determined by the more economical laboratory tests was correlated with the results obtained in the RTD jet engine test facility early in the program to minimize the amount of large scale testing required.

Material systems that performed reasonable well in the laboratory were then used to prepare nine foot diameter pads at RTD for testing under simulated landing and take-off operations with the Air Force J-85 jet engine test rig.

The results of the foregoing investigations are discussed in the sections which follow.

SECTION 2

DESIGN ANALYSIS

FLOW FIELD ANALYSIS

General Flow Field Conditions. Various agencies, investigating the flow field conditions generated by turbojet VTOL aircraft operating in close proximity to the ground, have defined the extremes of the environment to which an operational site will be exposed. The direct impingement of a high energy exhaust stream upon a flat surface has been examined by analytical methods and by direct tests. Analytical methods for the determination of finite values of pressure, velocity, and temperature for discrete points within the flow field have been devised (reference (3)). Other researchers have examined the mechanics of soil particle entrainment with the downwash flow field (reference (4)). It is recognized by most investigators that the work done to date is preliminary and that accurate estimates of exact flow field conditions are a function of many variables. For any specific aircraft, consideration must be given to such parameters as engine size, location, interaction between multiple engine nozzles, aircraft configuration, the influence of local terrain, local wind, flight profile, etc. While it is known that specific data points are difficult to determine, the over-all limits of the environment have been established and for the purpose of this investigation, the maximum conditions expected were used for site preparation design. For a turbojet powered VTOL aircraft, the following assumptions were made as to expected exhaust flow field conditions:

- Maximum exhaust gas temperature at ground surface:
  1500°F Military power setting
  3000°F Afterburner power setting

- Minimum height of nozzle to nozzle diameter ratio - H/D = 2

- Maximum surface dynamic pressure - q_s = 3000 psf

- Maximum radial velocity - 2500 fps

Analysis of J85-GE-5 Downwash Flow Field. The jet engine facility at the Air Force Aero Propulsion Laboratory, Wright Patterson Air Force Base, Ohio was utilized during the program to test specimen materials. This facility (figure (1)) uses a J85-GE-5 engine with afterburner that is capable of being rotated to a vertical position over test samples. The nozzle to specimen distance could be varied prior to start of testing. The flow field conditions generated were estimated by analytical methods for both the military power setting and the maximum afterburner condition. Figure (2) illustrates the decay of exhaust gas total temperature with distance from the jet centerline; predicts maximum wall jet flow field velocities expected as a function of distance from the jet centerline; and charts variations of dynamic pressure with distance from the jet centerline for military power. Figure (3) shows similar information for the afterburning condition.

Test Cycle for Take-Off Simulation. The time of exposure to elevated temperature of a site preparation material is a factor that greatly influences the ability of that material to survive repeated take-off and landing cycles. The take-off phase of a VTOL flight profile with the associated time factors for engine start, checkout, run-up, and lift-off was concluded to be more severe than the landing phase. To establish a realistic test cycle for use at the RTD jet engine facility, the downwash flow field generated by a hypothetical aircraft during the takeoff phase was examined with respect to time. Since lift off will occur when the engine thrust exceeds the aircraft weight, the analysis was begun at the time the engine reached its maximum takeoff power (time zero) and allowances were then made for other time factors in determining the test cycle.

Figures (4) and (5) present ground level temperatures and dynamic pressures that would be experienced from the vertical takeoff of a vehicle with 1.05 thrust to weight ratio at initiation of takeoff. Vehicle weight as a function of time is neglected. Figure (4) is based on a non-afterburning J-85 operating at military power setting during the take-off. Figure (5) has the same information based on maximum afterburning J-85 during takeoff.

Figure (6) presents a means of simulating the ground temperature and dynamic pressure of a takeoff by decreasing the power setting of a test engine which is at a fixed position above the ground.

To establish figures (4) and (5), the time-altitude relationship was established for the 1.05 thrust-weight ratio takeoff. The altitude at a given time was then expressed as a new H/D for the nozzle. For this H/D, the ground level temperature and dynamic pressure was established as shown in figures (4) and (5). Figure (6) was determined by transforming the values on figures (4) and (5) at a given time into an equivalent engine power setting with the nozzle fixed at the initial H/D value of 2.

A test engine throttle schedule was established for the RTD jet test facility, and is shown in figure (7), superimposed over minimum requirements established by figure (6). This is a conservative schedule exceeding the predicted takeoff environment. This schedule was used to evaluate nine-foot diameter specimens at the RTD jet test facility with the specimens being exposed to repeated cycles until failure occurred. Ten successive cycles of scheduled engine operations with a "cool down" period interposed between cycles was established as an objective.

ACOUSTIC ASPECTS

The predicted sound pressure levels generated by a J85-GE-5 engine are displayed in figure (8). The sound pressure levels were obtained by the methods of references (5) and (6) which are based on empirical measurements. The sound pressure levels generated by a one-inch diameter laboratory nozzle are shown in figure (8) and were also obtained by the methods of references (5) and (6), since references (7) and (8) indicate that model jets behave in the same way as full scale jets.

Figure (8) indicates that the laboratory nozzle will generate a sound pressure level ten laboratory nozzle diameters away which is equal in

magnitude to the sound pressure level generated by the J85-GE-5 jet at military power and ten J85-GE-5 nozzle diameters away. However, the J85-GE-5 jet noise is a maximum at 600 cycles per second whereas the laboratory jet noise is a maximum at 13,000 cycles per second.

The elasticity and viscosity coefficients of high polymers are sensitive functions of frequency and temperature; i.e., individual molecular resonances are activated. Reference (9) is one of hundreds which describe some of the microscopic mechanical responses of high polymers.

Since the viscosity and elasticity of high polymers are frequency dependent, their response to the high frequencies generated by the laboratory jet will be quite unlike their response to the relatively low frequencies generated by an aircraft jet. Therefore, an unrealistically lenient test may result from failure to include the low frequencies, and inclusion of high frequencies will result in a conservative test.

Theoretical analyses of the degree of conservativeness introduced into the test by the unavoidable high frequencies which would be generated by the proposed laboratory model jet were beyond the scope of this program. However, the results of the tests conducted in the RTD jet engine facility and with the X-14A aircraft, both of which utilized J-85 engines, did not indicate that acoustical fatigue was a limiting parameter.

SOIL MECHANICS

Surface soils can range from rock surfaces to the cohesionless sands of beaches or deserts to highly cohesive clays; contain moisture varying from the relatively dry to very wet condition; and be of varying permeability or absorbability of applied stabilizing liquids or compounds. Appendix A discusses soil deposits and characteristics as related to rapid site preparation.

SECTION 3

MATERIALS EVALUATION

APPROACH

The materials test program was concentrated on locating suitable materials for the relatively small central area of a VTOL landing site that is exposed to the extreme engine exhaust environment. The program employed simple laboratory screening tests using a natural gas fired torch to quickly and economically eliminate those materials which lacked the desired properties. These tests were followed by more severe evaluation tests using a modified plasma arc facility and later an oxy-acetylene cutting torch which produced high temperatures and a simulated jet engine exhaust environment. As the more promising materials were determined, specimens of these materials were fabricated at RTD by LTV personnel and then tested in the jet test facility operated by personnel of the Air Force Aero-Propulsion Laboratory.

Early in the program the need for modification of commercially available materials became apparent, and a materials development program was conducted concurrently with the screening tests. Many fillers and reinforcing materials were compounded with various base materials and tested. Physical and mechanical properties of the final selected material system were determined. The RTD jet test facility was modified to accommodate larger specimens, 9 ft. diameter, to provide a more realistic test than the earlier 2 ft. x 2 ft. specimens. Field evaluation of the final selected material system was accomplished at Moffett Field, California. The details of the field evaluation are given in Section 4.

SELECTION OF MATERIALS

The desirable properties of a material system to rapidly stabilize natural terrain so that jet engine powered VTOL aircraft could land and take-off without encountering the hazards of large quantities of dust, debris, etc., were established as follows:

Local air velocity	2500 ft. per second
Temperature	3000°F - 10 to 20 seconds
Soils	All classifications
Bearing strength	100 psi wheel loads
Viscosity (fluid systems)	100,000 centipoise (max. at 75°F)
Cure time	4 hrs. or less
Impact resistance	0.3 ft. lbs./in. (IZOD)
Tensile strength	6000 psi min.
Modulus of elasticity	300,000 psi min.
Heat distortion	500°F or above for 20 seconds
Burning rate	Non-flammable or self extinguishing with little or no smoke

Acoustical fatigue	150-165 decibels at random noise with peak at 600 cps
Weather resistance	6 months at surface temperatures 25-160°F

An industrial survey of approximately 100 leading manufacturers was made. Forty-seven responses, of which eighteen indicated possible suitable materials, were received.

The literature (reference (10)) was surveyed to determine the general classes of materials which might be suitable, and numerous technical brochures and periodicals were examined. Previous LTV research in the fields of ablative coating systems and VTOL rapid site materials was reviewed. Table 1 is a compilation of the generalized properties of a broad range of materials which were considered.

The base systems of primary interest were polyesters, epoxies, furanes, polyurethanes, silicones, phenolics, and ceramics. Previous LTV studies in the field of high temperature resistant plastic materials for hypersonic reentry vehicles (reference (11)) indicated that a modified polyester system not only had excellent thermal characteristics but good handling characteristics. Other studies of VTOL site materials (reference (12)) indicated that epoxy resins and ceramic cements could be modified to resist temperatures of 1500 to 3000°F respectively.

The modifiers or fillers considered were various metallic oxides which would alter the thermal conductance and/or form a glassine binder for the char resulting from flame impingement. Various metals and graphite were also considered as reducing agents, or as modifiers of thermal conductance and emittance. Boric acid, which had given excellent results in the earlier LTV work, was of prime interest.

The severe acoustic and mechanical vibration environment combined with the necessity for the site material to resist wheel loads of both VTOL aircraft and ground vehicles indicated the need for fibrous reinforcement. Three methods of reinforcement were considered:

- Dispersion of very short (0.5 in.) fibers within the resin or other binder.

- Spraying of short (2-6 in.) fibers with subsequent coating of resin or other binder.

- Spraying of continuous roving with subsequent coating of resin or other binder.

Fibrous materials of interest were: glass fiber, quartz fiber, asbestos fiber, potassium titanate fiber, aluminum silicate fiber, metallic fibers, and graphite fibers.

THERMAL AND EROSION RESISTANCE TESTS

Natural Gas Torch (1500°F). Preliminary screening of materials for resistance to flame impingement was accomplished with a natural gas fired torch. Flame impingement temperature was approximately 1500°F. Duration of each flame cycle was 30 seconds. Ten cycles constituted a complete preliminary screening test. It should be noted that this test procedure did not produce any effective velocity or pressure at the point of flame impingement.

The test panels were fabricated as 6 in. x 6 in. specimens. Approximately 285 grams of material to obtain a 2.5 lb. ft.^{2} area density was required. The density of the material determined the thickness. For most organic materials this was near 0.3 in. and for ceramic .187 to .250 in. thickness. (Figure (9))

Fibrous reinforcement was included in most of the specimens. Short fibers (less than 0.5 in.) could be mixed directly with the binder. Continuous fiber mats were simulated by use of swirl finish mating or by orienting individual fibers in layers with lengthwise directions 90° apart. Initial samples were fabricated over a soil base. This base was normally MIL-S-17726A silica sand, but was varied to include wet and dry clay in specific instances. Later samples were cast on a Teflon coated aluminum plate and removed for testing.

Plasma Arc (3000°F). Combined thermal and erosion testing was performed using a 40 KW plasma jet augmented by a high velocity air stream (figure (10)). This apparatus permitted the specimen to be exposed to high temperature and high velocity air simultaneously. The high velocity air was obtained by using an air source at 95 PSIG pressure exiting from a 0.0625 orifice.

Specimens (6 in. x 6 in.) were exposed for 20 seconds at 1500° impingement temperature and air velocity of approximately 2500-4000 ft./sec. for 20 seconds. The plasma torch was moved toward the specimen to produce 3000°F impingement temperature for a period of 10 seconds.

Approximately one hundred twenty-five specimens were tested in this facility. The ability of this test procedure to rank the relative effectiveness of materials appeared to be very good although some discrepancies from actual parametric conditions became apparent. The area of greatest erosive action did not appear to coincide with the area of highest temperature. Secondly, it was believed that the velocity decrease between the orifice and the specimen was too high to furnish the necessary scrubbing action which would be encountered with an actual jet engine. Therefore, a more satisfactory means of evaluation was used in later tests.

Oxy-acetylene Torch (3000°F). A conventional oxy-acetylene cutting torch was mounted on laboratory ring stands as shown in figure (11). This arrangement permitted ready adjustment of specimen to torch distance as well as good flame characteristic control.

The primary advantage of the cutting torch over the plasma arc was the coincidence of the area of maximum temperature with the area of maximum pressure-velocity.

The torch tip was constructed with multiple low pressure orifices located in a circle around a central high pressure orifice. In operation, the test procedure was as follows:

- Adjustment of torch. A 6 in. x 6 in. ceramic plate was placed on the ring stand and the torch ignited. The flame was adjusted to produce approximately 3000°F with the high pressure oxygen (cutting) valve closed. A ceramic plate was used for calibration to minimize ablative effects. Temperature readings were made with an optical pyrometer. The torch was then quenched.

- Specimen test. After replacing the ceramic plate with a 6 in. x 6 in. specimen, the torch was ignited as before and allowed to preheat the specimen for 20 seconds. The cutting gas valve was locked open for ten seconds allowing a 100 PSIG stream of oxygen gas to impinge upon the specimen through a .125 in. diameter orifice. Both oxygen and acetylene valves were closed simultaneously to complete the cycle. This cycle was repeated after approximately three minutes cool down without disturbing the specimen thus maintaining the same point of impingement throughout the test of a given specimen. Approximately 50 specimens were tested in this manner.

Torch test specimens of all types were observed for the following:

- Number of cycles to burn through.

- Residual flame after removal of torch.

- Residual smoke after removal of torch.

- Appearance after firing.

- Material handling properties.

The material systems evaluated and results of these tests appear in table 2.

RTD JET TESTS

Figure (1) shows the RTD jet test facility which was used for the final evaluation of promising material systems. The first four specimens fabricated were 2 ft. x 2 ft. and the latter four were 9 ft. in diameter. The 9 ft. diameter test specimen provided a more realistic test with the engine inlet being protected by a stainless steel screen to prevent any injection of debris. The results of these tests are summarized in table 3.

Test RTD-LTV 1. The initial test specimen was fabricated within a steel enclosure designed to prevent damage to the J85-GE-5 engine should catastrophic failure of the pad occur. Specimen size was 2 ft. x 2 ft. Composition of the specimen was as follows: 5 lb. Hetron 353 polyester resin, 3.6 lb. boric acid, 80 gm. fiber glass roving, and 60 gm. methyl ethyl ketone peroxide. The roving was distributed by hand over a prepared

Table 3

Summary of Results of RTD-LTV Cooperative Tests in RTD Jet Test Facility

Test Number	Material Type	Specimen Size	Area Density lb./ft.^{2}	Number of Cycles to Failure	Total Running Time (Sec)	Total Afterburner Time (Sec)	Remarks
RTD-LTV 1	Polyester Borate	2 x 2 ft.	2.5	6	134	44	Failed at Corner
RTD-LTV 2	Polyester Borate Alumina	2 x 2 ft.	2.5	3	90	30	Failed at Metal Contact
RTD-LTV 3	Ceramic Gel (Siroc)	2 x 2 ft.	2.5	1	-	-	Material Did Not Fully Set.
RTD-LTV 4	Zirconia (Rusco BX750)	2 x 2 ft.	2.5	1	-	-	Delaminated Immediately
RTD-LTV 5	Polyester Borate	9 ft. Diameter	5	9*	180	54	*No Failure Occurred
RTD-LTV 6	Polyester Borate	9 ft. Diameter	2.5	10	220	60	Completed Target Number of Cycles
RTD-LTV 7	Siroc	9 ft. Diameter	2.5	**			**Not Tested. Did Not Set Sufficiently.
RTD-LTV 8	Polyester Borate	9 ft. Diameter	-	1	30	6	Poorly Fabricated Over Sod

base of packed clay and sand mixture. The remaining materials were mixed and poured over the roving mat.

After curing three hours the pad was subjected to jet engine exhaust environment as follows:

Cycle No.	Running Time (Sec.) Total	Afterburner	Maximum Gas Temperature at Sample (°F)
1	29	10	2160
2	10	1	1770
3	28	10	2230
4	27	10	2200
5	28	10	2160
6	15	3	1180

Failure of the specimen occurred during the sixth cycle. Illustrations of this specimen before and after firing are shown in figure (12).

Test RTD-LTV 2. A 2 ft. x 2 ft. specimen was fabricated from the following materials: 5 lb. Hetron 353 resin, 2.15 lb. alumina bubbles, 1.93 lb. boric acid, .35 lb. glass mat, .35 lb. methylethyl ketone peroxide. The specimen was cured 3.75 hours at approximately 65°F.

The specimen was subjected to the exhaust of the J85-GE-5 engine. Each cycle consisted of approximately 30 seconds total running time of which 10 seconds was at afterburner power. This specimen failed on the third cycle.

Test RTD-LTV 3. A 2 ft. x 2 ft. specimen was fabricated using the SIROC ceramic gel system. This system was composed as follows: 7.5 lb. SIROC No. 1, 1 lb. SIROC No. 2, .4 lb. glass mat and 1 lb. water from Dayton water supply. This material coagulated during mixing and was spread manually over the mat. After 25.5 hours, the material had not fully set. The specimen was tested at this time, however, in order to observe the effects of the jet engine blast on the jelled material and determine if the heat would cause nearly instantaneous setting of the gel. The specimen failed during the first cycle.

Test RTD-LTV 4. A 2 ft. x 2 ft. specimen was fabricated by pouring a mixture of 6.66 lb. of Rusco BX750 powder and 3.33 lb. of BX750 liquid over 80 gm. of glass mat. This specimen was cured for over 24 hours and tested under the J85-GE-5 engine. The specimen delaminated and failed during the first cycle.

Test RTD-LTV 5. A nine ft. diameter pad was fabricated in the following manner.

Fiber glass roving was sprayed in a continuous swirl pattern using the glass spraying apparatus described in Section 5. The resin binder was mixed by hand in small batches. Each batch consisted of 14.0 lb. Hetron 353 resin, 8 lb. boric acid, 1.375 lb. antimony trioxide, .375 lb. methyl ethyl ketone

peroxide. This mixture was sprayed over the glass roving. Resin and glass fibers were alternately sprayed on the pad to form a reinforced simulated site. Final site area density was 5.0 lb./ft.^{2} of which approximately five percent was fibrous reinforcement. The specimen was cured 3.5 hours before testing. Total elapsed time from initial fabrication was 4.5 hours. (Slight shrinkage of the specimen prompted the addition of an epoxide filler at the edge of the pad to minimize edge effects. This delay resulted in the somewhat long cure time noted above.)

The specimen was tested under the exhaust of the J85-GE-5 engine. The test profile shown in figure (7) was used except for the first run which had three seconds less afterburner time. A total of four runs at 63.5 in. engine to specimen distance were conducted during the first day of operation.

On the following day the engine to specimen distance was lowered to 53.5 in. Four tests were run for an additional 80 seconds of total time and 24 seconds of afterburner time to that run previously.

The engine to specimen distance was lowered to 36 in. or approximately two engine diameters. One run was performed but excess intake temperature prevented further testing at this height.

There was no failure of this specimen. Some buckling and slight charring occurred but did not appear to affect the functioning of the pad. An area approximately three ft. in diameter turned cherry red on the surface during each test. This produced an area of light char which extended a maximum of 43 in. from the centerline of the engine. This specimen is shown in figure (13).

Test RTD-LTV 6. This specimen was fabricated in a similar manner as RTD-LTV 4 except the area density was only 2.38 lb./ft.^{2}. This specimen was cured 2.5 hours after pouring.

The first test was conducted with the engine 65 in. from the specimen. This test consisted of full military power for 60 seconds. Tests 2 and 3 were approximately 20-30 seconds total with 6 seconds afterburner each run. Tests 4-10 were similar except that the engine height was set at 53 in. from the specimen.

Burn through occurred at the end of the tenth cycle. The area of failure was limited and no large scale disintegration of the specimen occurred.

Test RTD-LTV 7. An attempt was made to fabricate a SIROC fiber glass 9 ft. diameter specimen. However, the low viscosity of the SIROC caused it to run to the lowest areas leaving high spots bare. Much of the material flowed over the sides of the specimen support. This material failed to harden sufficiently to test.

Test RTD-LTV 8. The specimen was fabricated in a manner similar to LTV-RTD 4 except that a sod base was used. This pad was poorly fabricated as a result of water in the compressed air supply. The specimen failed on the first cycle.

PHYSICAL AND MECHANICAL PROPERTIES TESTS

Physical and mechanical properties were determined for a reinforced polyester resin system which was selected as a result of the thermal and erosion resistance tests. Beam flexural specimens were used to evaluate the effects of different environments on the principal formulation (Formula A) and selected variations thereof. The composition of Formula A is shown below:

Hetron 353 Polyester Resin	56%
Boric Acid	32%
Antimony Trioxide	5.5%
Glass Fiber	5% (Nominal)
Methyl Ethyl Ketone Peroxide	1.5% (Nominal)

In addition, compression buttons, tensile coupons, and transverse shear beams were utilized to determine specific properties of the Formula A system. The results are given in table 4.

Flexure Beams (ASTM D 790). These specimens (figure (14)) were cast on a 6 in. x 6.5 in. Teflon coated plate. The continuous filament fiber glass roving was uniformly distributed with alternate layers 90° apart. This precaution was taken in order to effectively isolate the effect of the variation being studied. Each sample was removed from the plate somewhat prior to the selected test time and cut in 0.5 in. x 6.5 in. specimens. Specimen thickness for 2.5 lb./ft.^{2} area density was approximately 0.3 in.

At the designated test time, the specimens were tested in flexure. The test span was 6.0 in., and the loading rate was 2 in. of deflection per minute. Flexural modulus was determined from the load deflection curve.

Compression Buttons. Circular specimens, one square inch in area were cut from the 6 in. x 6.5 in. castings previously described under flexure beams above. After curing four hours, these specimens were loaded in flatwise compression at a loading rate of 4000 lb./min. The maximum limit of the Baldwin test apparatus was 9500 lb.

Transverse Shear. Specimens 2 in. x 8 in. x 0.3 in. were loaded in transverse shear after four hours cure. Major span length was 6 in. and minor span was 4 in.

Tensile (ASTM D 638). Tensile specimens were cut from 6 in. x 6.5 in. samples. The specimens were pulled in tension on a Baldwin tensile machine at a loading rate of 4000 lb./min.

TABLE 4
Properties of Formula A Material System
After Four Hours Cure

Transverse Shear Strength	14,160 psi
Tensile Strength	4,100 psi
Flexural Strength	9,500 psi
Flexural Modulus (at 50% of failing load)	475,000 psi
Maximum Deflection, on 6 in. span	.73 in
Compressive Strength	> 9,5000 psi

Viscosity of Uncatalyzed Resin. Viscosity of the Formula A system was determined at various temperatures between 40°F and 84°F using a Brookfield Viscometer. This curve is shown in figure (15).

Compressive Strength vs Time at 75°F. Compressive strength was determined on the Formula A system as previously described at various time intervals between 0.5 and 4 hours. This curve appears in figure (16).

Flexural Strength and Modulus vs Time at 75°F. Formula A flexural beams were tested at intervals between 0.5 and 4 hours. These results appear in figures (17) and (18).

Effect of pH and Water on Flexural Strength. Formula A flexural specimens were cast on blotters saturated with one of the following pH value solutions 5, 7 (distilled water), or 9. After curing four hours, the specimens were tested in flexure. These curves appear in figures (19) and (20).

Effect of Catalyst Concentration on Gel Time. The gel time was determined at 32°F, 75°F, and 105°F for three different catalyst ratios, 0.5, 1.5, and 3%. Gel time was taken as the time required for the material to become essentially solid. A relatively sharp gel end point (± one minute) was observed in all cases except the low catalyst, low temperature combination. These curves appear in figure (21).

Effect of Variation of Boric Acid Filler Content. Flexural specimens containing various percentages of boric acid between 15% and 32% were tested after four hours cure time. All other parameters were held constant. The results of these tests appear in figures (22) and (23).

Variation of Fiber Glass Content. Flexural specimens were prepared with continuous filament fiber glass roving content varying between 4% and 10%. The specimens were cured four hours and tested as before. These curves appear in figures (24) and (25).

DISCUSSION OF RESULTS

Thermal and Erosion Tests. Material systems which completed at least ten cycles of the plasma arc or six or more cycles under the oxyacetylene torch were considered promising. The ten cycle figure was the original target number of cycles. In order to provide a correlation point, the oxyacetylene torch was adjusted to produce a failure in six cycles of a specimen having identical composition as the RTD-LTV-1 specimen which failed in six cycles under the J85-GE-5 engine. Representative specimens after exposure to the plasma arc or the oxyacetylene torch are shown in figures (26) through (31).

Several ceramic specimens of the zirconia class exhibited good flame-erosion resistance (Table 2). However, observation of the specimens indicated poor wetting of the glass fibers and slow curing rates were experienced. Even though the material had set sufficiently for testing within four hours, the system appeared to still be in a "green" state and would probably have possessed poor mechanical properties at that stage. Handling properties while moderately good for laboratory specimens would have posed difficulty in the field. This is based on the fact that large quantities of dry powder would have to be mixed with a liquid just prior to dispensing.

Ceramic gel systems such as SIROC yielded good flame-erosion resistance when tested after reaching a solid state of cure. Attempts to promote solidarity in four hours were unsuccessful. During tests at RTD the material was found to be too fluid for simulated field application. In addition, the sensitivity of this material to water parameters such as pH, dissolved gas or other minute impurities prevented solidification when mixed with Dayton, Ohio water as compared with Dallas, Texas water.

Of the epoxide systems tested, only one specimen (138) displayed adequate flame-erosion resistance. Two other specimens of this system (136, 137) produced internal cracking due to excessive exotherm and were short lived under the oxyacetylene torch. This system was adjudged to be too critical for practical application due to sensitivity to catalyst concentration and/or temperature.

Specific samples of furane type resins displayed adequate flame-erosion resistance when cured a sufficient length of time (12-48 hours). Attempts to reduce the cure time resulted in excessive exotherm and a subsequently porous material. The Durez 16470 system used a powdered catalytic system which would pose additional problems in field application.

The Dow Corning silicone, RTV 589 with RTV 502A catalyst is an example of an elastomeric system which resisted the flame-erosion tests. This system, however, could not be fully cured within the prescribed limits. (Gel time was within target of four hours.) This material was considered to have relatively poor handling characteristics for large scale field applications.

A number of chlorinated polyester resin based systems yielded adequate flame-erosion resistance as well as displaying good application characteristics. These systems produced a tenacious char which was strengthened by a glassine binder formed from the filler and reinforcement material. The selection of the boric acid-antimony trioxide filler system was based

largely on the over-all handling and heat resistance properties. Inclusion of extraneous materials such as alumina bubbles proved to be degrading. While cost would be relative to the quantity of material required for field use, this system appears to be one of the least expensive of those investigated.

Prefabricated systems were investigated up to the point where field handling problems appeared to outweigh any singular advantages of these materials. A prefabricated phenolic asbestos board supplied by Quality Materials Corporation displayed excellent flame-erosion resistance. This type of material would be worthy of further evaluation if prefabricated concepts were to be further explored. Phenolic materials in general would have to be integrated into a prefabricated system due to the manner of cure. Phenolic resins produce volatiles which result in porous materials where proper pressure and/or volatile removal cannot be effectively accomplished. Attempts to cure the QMC phenolic material used above by free pouring rather than pressure molding resulted in a porous material with poor flame-erosion resistance.

RTD Jet Tests. The RTD-LTV 1 indicated that the polyester-borate material system might provide the desired properties. However, the RTD-LTV 2 test was most disappointing. A review of the mode of failure indicated that the test configuration presented an unrealistically harsh environment. Since the small 2 ft. x 2 ft. specimen was enclosed in a metal box inside an exhaust duct, the desired ablative characteristics of the material system were negated primarily by edge effects. As demonstrated in later tests, the RTD jet test facility is an excellent evaluation tool when used with the 9 ft. diameter specimen.

Specimen RTD-LTV 5 was not tested to failure as the pad was approximately twice (5 lb./ft.^{2}) the desired maximum area density and showed very little deterioration after a total run time of 180 seconds. Rather than continue testing this specimen, specimen RTD-LTV 6 was prepared and successfully tested.

The lack of success of RTD-LTV 8 is attributed to the specimen fabrication. Sufficient water was present in the compressed air supply to saturate much of the fiber glass roving used as the reinforcement in the pad. While a pad may be fabricated over wet soil, wet fiber glass will prevent the proper bonding of fiber glass and resin creating a weak pad structure.

Physical and Mechanical Properties. The viscosity range of the selected material (Formula A) varied from 20,000 centipoises at 40°F to 2,000 centipoises at 84°F. (Figure (15)) This readily allowed pumping of the material with no adjustment of equipment over the probable range of application temperatures.

The flexural strength vs time curve (figure (17)) indicates a rapid rise in strength during the first hour and a slight gradual increase thereafter. Compressive strength indicates a similar rise except increase occurs to at least two hours. At two hours, the material failed in compression at the extreme limit of the test apparatus. No compressive failure occurred at

the limit after four hours of cure time. The fact that the material is substantially cured after two hours is also indicated by the flexural modulus curve (figure (18)).

The effect of moisture and pH on the four hour flexural strength appears to be negligible (figure (20)).

The formula A material system yielded adequate working time and sufficiently rapid cure time at normal temperatures (70 - 95°F). Figure (21) indicates that extremely high temperatures (105°F) yield very short gel times. Operation at such high temperatures may require reduction in the promoter content or implementation of catalyst injection at the nozzle. The low temperature curve indicates that cure will be executed in a reasonable length of time except in the case of the very low catalyst ratio (0.5%). Increasing promoter concentration for areas of very low temperature operation may be beneficial. Information is available which suggests that similar systems have been cured at temperatures as low as -25°F by increasing the promoter concentration, i.e., cobalt naphthenate and dimethylanline.

Investigation into variations of the Formula A formulation indicates that maximum flexural strength is obtained at a somewhat lower loading (20%) of boric acid than the 32% used (figure (22)). However, the flame-erosion resistance is higher than with a 20% loading.

Inclusion of additional glass fiber (figure (23)) tends to increase the strength of the system. The problem of wetting out greater quantities than 5% glass fiber requires a great deal of skill on the part of the operators. Therefore, somewhat less than maximum glass content would probably be more practical for field application. Continuous filament fiber glass roving was determined to present the least problem for field handling. Continuous filament roving can be directed accurately and requires the operator to handle only light weight dispensing equipment. Chopped fibers with resinous overcoat require more elaborate equipment and are difficult to handle in the field, particularly if any surface wind is present. Blending of shorter chopped fibers with the resin usually results in a tenaciously gelled material which is difficult to pump.

The processes utilized in laying full scale sites appeared to be relatively free from hazardous operation. The spray system functioned in such a manner as to preclude the likelihood of human ingestion of materials by breathing or other means. The ventilation provided by an open field obviously reduces this problem to negligibility. Eye protection and sensible clothing (coveralls) appeared to be adequate for most operations. Rubber or plastic gloves and aprons would be beneficial for personnel with sensitive skin. The base resin material contains styrene monomer and carries the label,"CAUTION: May cause irritation, avoid prolonged contact with the skin, avoid prolonged breathing of vapor. Use with adequate ventilation." Ingestion of antimony trioxide blended in the resin is highly unlikely. However, this material is somewhat toxic. The oral LD_{50}* in rats is greater than 20 gm./Kg. This is approximately 200 times less toxic than the related arsenous oxide. Ingestion of boric acid should be avoided also. This material has an LD_{50}

*LD_{50} - Lethal dose required to kill 50% of participating animals.

in rats of 3 gm/Kg. Generally speaking, use of this material should receive the same precautions as are commonly observed with paint type materials.

While no specific weathering tests were performed per se, a degree of speculation may be advanced toward the probable weathering characteristics of this system. In addition, observation of a simulated landing site at LTV, Dallas, Texas and the enlarged landing site at NASA, Moffett Field, California has yielded some actual weathering data. The LTV site observation indicates no superficial effects other than some migration of the high temperature resistant additive to the surface after approximately two months exposure to Texas wind and weather. NASA has unofficially reported fine (superficial) cracks in the site at Moffett Field after three months exposure. The basic resin reportedly has excellent chemical and water resistance. While the resin itself has good solar radiation resistance, the addition of antimony trioxide increases the opacity of the system and tends to increase the protection of all but the outermost layer of material from the effects of sunlight. Boric acid, however, in the free state tends to be hydroscopic. This property could be detrimental to the longevity of the cured system. It is possible, however, that encapsulation of each boric acid particle by the base resin will significantly retard or prevent this phenomena. No observations of freeze-thaw effects were possible. Laboratory panels indicate that no direct effects on the material result from freezing.

SECTION 4

OPERATIONAL FIELD SITE

SUMMARY

Based on successful test results obtained during the material development program, the decision was made to conduct full scale field demonstration tests which would include flight operations with a turbojet VTOL aircraft. A cooperative test program was arranged with the NASA, Ames Research Center, Moffett Field, California for operational testing of the rapid site preparation material system with the X-14A turbojet VTOL research aircraft. The over-all program was coordinated with NASA, Ames by the Air Force Aero-Propulsion Laboratory.

The objectives of this program were:

- Fabricate and demonstrate experimental application equipment capable of rapidly preparing remote sites for turbojet VTOL aircraft operations.
- Develop and demonstrate material application techniques.
- Conduct repeated flight operations with the X-14A aircraft to evaluate the resistance of the material system to the downwash environment of that aircraft.

These tests were successfully completed during June 1964 at Moffett Field, California.

APPLICATION EQUIPMENT

An application system was designed and fabricated for pumping and spraying the resin mixture and the fiber glass reinforcing material. This system was mounted on a standard Air Force 4 x 10 ft. four-wheeled dolly (figure (32)).

The liquid pumping unit consisted of a constant displacement pump driven by a nine HP gasoline engine. Appropriate gear reduction was used to provide a flow rate of two to six gallons per minute depending on engine throttle setting. The liquid mixture was pumped through a one-inch diameter hose to a fixed orfice nozzle which provided a fan shaped spray.

The fiber glass reinforcement was applied with a continuous filament dispensing system.* This system consisted of a pressurized container, a compressed air source, a closed conduit, and a dispensing gun. In operation a roll of fiber glass roving was inserted into the pressurized container and the roving introduced into the conduit. Compressed air was applied so that upon opening the gun, the fiber glass was transported through the conduit and out of the gun. Figure (33) shows a typical glass gun in operation. A three horsepower compressor was used to provide air at approximately 25 psi at 5 cfm.

*Patented system by The Archilithic Company, Dallas, Texas

The resin mixture was catalyzed prior to pumping. Power for the catalyst mixer was supplied by a 1000 watt portable alternator. A paint pressure pot containing acetone was utilized to flush the system.

An equipment trial was conducted at the LTV facility prior to the field tests at Moffett Field. A semicircular site was prepared approximately 25 ft. in diameter (reference figure (34)). One quarter of the site was sprayed at a rate of 1 lb./ft.^{2} to represent a dust cover area and the other quarter at approximately 4 lb./ft.^{2} to illustrate a primary central pad. The terrain selected for the trial contained both hard dry bare soil and grass and weeds 4 to 6 in. high. All equipment operated satisfactorily. Spray rates of both the resin application and the fiber glass dispensing unit were regulated, and techniques were developed for maintaining desired membrane thickness.

MATERIALS

The resin formulation (Formula A) was premixed at LTV in ten gallon containers. Each drum contained 93.5 lb. of mixture such that the addition of catalyst and fiber glass would make 100 lb. of site material. Each drum was restirred to place the solids into suspension, and just prior to being pumped onto the site, a sufficient amount of catalyst was added and mixed thoroughly. Pumping was accomplished directly from each drum. MEK peroxide catalyst was used at a ratio of 0.3 of 1% of the total mixture weight. The fiber glass reinforcement was supplied in 32 lb. rolls of 34 ends roving and dispensed in the continuous filament form.

CREW REQUIREMENTS

A crew of five was used to fabricate the demonstration sites at Moffett Field. Three crew members were necessary at the trailer to catalyze the liquid mixture and to keep the pumping unit supplied as drums were emptied. A fourth crew member sprayed the liquid mixture while the fifth dispensed the fiber glass.

SITE FABRICATION

The site was selected adjacent to a concrete runway to minimize risk to the test aircraft in the event an unexpected failure of the pad occurred. The site was prepared over an area of loose, dry California adobe top soil, essentially level, and containing exposed rocks 2 to 3 in. in diameter. All vegetation had been removed from the area by discing the top surface to a depth of four inches and then leveled by dragging. Initially a pad 25 ft. in diameter was applied at a rate of 4 lb./ft.^{2}. A 7 ft. dust cover was added to the periphery of this pad at a rate of approximately 1 lb./ft.^{2}. (In subsequent operations, this dust skirt was extended to 17 ft. in width.) Figure (35) shows the site being prepared. Fabrication sequence for preparation of the site was as follows:

Time	Event
0825	Equipment on site.
0830	Layout outline of site.
0905	Prime pumps.
0910	Catalyzed first drum.
0911	Started glass and resin spraying.
0930	Completed 25 ft. diameter first coat (800 lb.)
0948	Completed 25 ft. diameter - second coat (total 1600 lb.)
0949	Flushed system and shut down equipment.
1000	Pad inspection and installation of thermocouples.
1100	Started spraying of 7 ft. wide dust cover.
1108	Dust cover complete (total 1900 lb.)
1108	Started final coat on 25 ft. diameter site.
1119	Site completed - flushed system (total 2300 lb.)

The site required 2300 lb. of material of which 300 lb. were for the dust cover. The total elapsed time of fabrication, from the time equipment was on site until the site was complete, was 2 hours 54 minutes which included a one hour down time for inspection and installation of instrumentation thermocouples. Therefore, actual construction time was one hour 54 minutes for the 39 ft. diameter site. The material was set up and tack free in approximately 12 to 15 minutes and cured to an adequate strength level in one hour after completion of spraying.

After the initial flight test operation, the site size was increased to more adequately control dust generated at the edges. An additional 10 ft. wide dust cover strip was added around the site. Fabrication of this strip required 32 minutes and 1000 lb. of material. This increased the total site fabrication time to 2 hours 26 minutes, and the total material weight to 3300 lb.

The technique used during fabrication consisted of first applying a layer of fiber glass to the surface of the ground over the first quadrant of the circle. This glass layer was then overcoated with the resin mixture. The remaining thickness was obtained by simultaneous applications of glass and resin to insure wetting of all glass reinforcement and provide a homogeneous mat buildup. Successive quadrants were covered in a like manner with the glass reinforcement being allowed to overlap into adjacent quadrants to maintain structural continuity. A final touch-up application was made to insure that no voids were present in the primary pad area.

VTOL OPERATIONS AND RESULTS

The aircraft furnished by NASA, Ames was the X-14A VTOL research airplane. This aircraft is powered by two vectored thrust J85-GE engines mounted

horizontally in the fuselage. The aircraft had a gross weight of approximately 3500 lb. The main gear had a tread width of 10 ft. 7 in. and was equipped with 6.50 x 8 tires inflated to approximately 40 psi.

The initial flight test was begun approximately 1 hour 10 minutes after completion of site preparation. The ambient temperature was 86°F. The first pass over the site was from the taxiway side at an altitude of approximately 40 ft. Hover flight above the site produced moderate dust which was generated from the unprepared areas adjacent to the prepared site. The aircraft decended to approximately 12 ft. above the pad and the dust generation increased rapidly. During the let-down from 40 to 12 ft. the aircraft drifted near the east edge of the 25 ft. diameter basic site producing extremely heavy soil erosion in the vicinity of the dust cover on that side. Soil was eroded thru pin holes in the dust cover cavitating an area beneath the dust cover approximately 3 ft. diameter by 3 in. deep. Additional erosion occurred in the unprepared area at the edge of the dust skirt. The dust cloud generated was dense and extended vertically to the height of the aircraft. Dust and debris were blown over a 60 ft. diameter. Light dusting was observed above the aircraft. Flight tests were concluded and the following site changes were accomplished:

- The dust cover was lightly oversprayed and was extended to 17 ft. in width.

- Two visual reference markers were placed in line with the pad centerline approximately 100 ft. and 200 ft. respectively from the center of the pad to assist the pilot in maintaining the aircraft directly over the pad during hover.

Flight tests were resumed the following morning. The first pass consisted of hovering at altitudes from 40 to 3 ft. above the pad. No dust or effect on the pad was observed (figure (36)). On the second pass hovering descent was made until the wheels were only one ft. above the pad. Thermocouples located at the pad centerline recorded approximately 1500°F, and a light charred area approximately 2 1/2 ft. in diameter was produced at the center of the pad. Several hover flights were then made from 30 ft. altitude with descent to touchdown followed by lift-offs. Two landings and engine shutdowns were made. Prior to the second shut-down the engines were run at 90% power for 60 seconds (figure (37)). The aircraft was towed off the pad by a standard tow tug. An inspection of the pad revealed a 1/32 in. deep charred area approximately 6 ft. x 8 ft., but the pad was unaffected otherwise (figure (38)). A slight heat buckle developed at the center of the pad as a result of the 90% power engine run, but the pad remained flexible and was not damaged by the wheel loads imposed by the tug.

The next flight operation involved passes over the site to determine the edge effect of downwash on the dust cover. The aircraft hovered at 30 - 35 ft. altitude for approximately 30 seconds above the extreme edge of the dust cover. Soil erosion was very heavy, and as the soil was eroded from beneath the 17 ft. dust cover, a sector of approximately 120° arc was blown out. The aircraft downwash produced a dense dust cloud while over the bare terrain. (Figure (39))

The remaining materials were then used to repair the damaged dust cover and to enlarge the site. Figure (40) shows the layout of the original site and figure (41) shows the enlarged site. The enlarged site, 59 ft. x 62 ft., utilized a total of 6,000 lb. of material and had a cumulative construction time of 3 hrs. 56 minutes. No further flight tests were conducted due to unavailability of the test aircraft.

DISCUSSION OF RESULTS

The major problem encountered during the field demonstration program was the failure of the solids in the resin mixture to remain in suspension. Upon arrival at Moffett Field, the solid materials, boric acid and antimony trioxide that were mixed with the resin prior to shipment, were found to have settled out and compacted in the bottom of each container. It is believed that the road vibration and high temperatures experienced during the truck transport from Dallas, Texas to Moffett Field, California were the primary causes. Extensive hand labor was required to stir these components back into suspension.

The experimental application equipment performed satisfactorily in all respects and demonstrated the feasibility of the fabrication technique. Since the application equipment pumped a fully catalyzed resin system, working time was critical. Due to the fairly high ambient temperatures (75-95°F), it was necessary to reduce catalyst from a nominal 1.5% to 0.3 of 1%. Figure (21) shows the effect of catalyst concentration and temperature on gel time.

As anticipated, the over-all site demonstrated resistance to high temperatures and dynamic pressures for repeated landings and takeoffs. The depth of the char and the area of the char produced during the tests correlated closely with the results previously obtained with 9 ft. diameter pads tested at military power in the RTD jet test facility. (Specimen RTD-LTV-6) It is noted that the basic site was fabricated at 4 lb./ft.^{2} while the RTD test specimen was less than 2.5 lb./ft.^{2}. It seems reasonable, therefore, that similar results would have been obtained if the basic site had been 2.5 lbs./ft.^{2}.

The wheel loads imposed by the X-14A aircraft were insignificant due to the low gross weight and low tire pressure. It is noted that a standard tow tug moved across the site, including the heat affected area, without causing any damage.

The initial size of the basic site was selected arbitrarily as 25 ft. diameter. This was considered to be the minimum adequate to protect the terrain in the area of the high temperature, high dynamic pressure downwash. Consideration was also given to the aircraft configuration, landing gear placement, and slight deviations in aircraft position relative to the center of the site during descent. A minimal dust cover 7 ft. in width was then added to the periphery of the basic site with subsequent increases in the dust cover to be made only as indicated by flight test results. Initial hovering flight at 40 feet altitude immediately showed that the total site

was of inadequate size. Since the actual air velocity which occurred at ground level is not known, it can only be assumed that the site was of insufficient size to protect enough terrain from critical velocities which caused large amounts of dust to be created. This problem was further aggravated by the lack of visual references to allow the pilot to maintain an accurate alignment with the center of pad.

The subsequent addition of a larger dust cover, making the total site 59 feet in diameter, and the placement of visual reference markers provided a site that was successfully demonstrated to be adequate for hover, landing and takeoff of the X-14A aircraft. True vertical descent of the aircraft from the approach altitude of 40 ft. was required. Since the tests were conducted over one of the most severe soil conditions, it is believed that smaller site areas over many other types of natural terrain would be practical.

The hovering flight during which damage to the dust cover occurred illustrated that below a certain altitude (in this instance approximately 50 ft.), the aircraft must be accurately positioned over the pad to prevent erosion under the edge of the dust cover which may lead to failure of the cover. This same problem would also exist when an aircraft makes an approach to the landing site at low altitude or when descending on other than a near vertical flight path.

It was suggested by NASA personnel that the site provide for landing with a VTOL aircraft at an approach angle other than true vertical to minimize the hazards arising from engine failure. (This situation would not exist for VTOL aircraft having "engine-out" capability.) This constraint would affect site size and make some form of approach strip necessary. The extent of this ground protection would depend on the natural resistance to erosion afforded by the terrain and vegetation in the area.

The final site configuration (figure (41)) incorporated an approach strip 20 ft. wide. This strip was fabricated in sections of varying thicknesses from 3 lb./ft.^{2} adjacent to the basic site to 1 lb./ft.^{2} at the dust cover. Further flight tests are required to evaluate the adequacy of this approach strip to resist the downwash from an aircraft whose landing flight path is other than true vertical.

It should be recognized that the size of the over-all site is most critical from the standpoint of total material weight, and obviously logistics, when remote advanced sites are considered. Figure (42) shows that the total site weight goes up drastically with increases in diameter even though the basic site area is relatively small compared to the total site area. This means that flight operational techniques may be the most significant site parameter.

Certainly, in view of the large potential penalties in site size, weight, and preparation time associated with non-vertical approach conditions, consideration must be given to operational techniques and visual cues that will minimize the need for such approaches.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- A sprayable rapid curing light weight low cost material system for use as a remote landing and takeoff site for turbojet VTOL aircraft is feasible.

- A chlorinated polyester resin system modified with temperature resistant additives and fiberglass reinforcement is suitable for use as a VTOL landing site which will be exposed to the erosive high temperature, high dynamic pressure exhaust environment of an afterburning turbojet engine.

- It is believed that the basic VTOL landing site area exposed to the severe temperatures and velocities of a jet engine exhaust can be fabricated using a maximum of 2.5 lbs./ft^2.

- The polyester resin-fiberglass roving mixture sprayed on loose soil as a light weight (approximately 1 lb/ft^2) dust cover surrounding the basic landing mat was demonstrated to be effective.

- The use of a nine foot diameter specimen in the RTD jet test facility was established and provided a most effective means of evaluating VTOL landing site materials in the exhaust environment of a J85-GE-5 engine.

- A small scale laboratory screening test was established which could essentially duplicate the mode of failure and the number of cycles to failure in the RTD J85-GE-5 jet test facility.

- The effects on the VTOL landing mat resulting from limited flight operations of the X-14A were similar to those obtained with specimens tested in the RTD jet test facility.

- The only significant disadvantage with the material system developed for VTOL landing sites is the tendency of the pre-mixed temperature resistant additives to settle out of the resin base when transported or stored for any appreciable time.

- Because of its experimental nature and the catalyzing method employed, the fabrication of the operational field site at Moffett Field, California required more personnel and supporting equipment than desirable for advanced VTOL site operations.

- While several material systems such as: ceramics (zirconia and gel), epoxides, furanes, silicones, and phenolics, exhibited good flame-erosion resistance, other disadvantages existed. The primary disadvantage was long cure time. In the case of phenolics, only prefabricated specimens made by pressure molding showed promise. The

ceramic gels were too fluid and sensitive to water pH. The epoxides were so sensitive to catalyst concentration and/or temperature as to be impractical. The silcones had relatively poor handling characteristics.

RECOMMENDATIONS

- The filled chlorinated resin system developed for VTOL landing sites should be optimized with particular emphasis on methods to eliminate the separation of the fillers from the base resin. Since any modification in the formulation may affect the desirable properties of the material system for VTOL landing site fabrication, additional laboratory testing and evaluation in the RTD jet test facility will be required.

- Investigations of various catalyst injection methods and two part resin systems should be conducted to develop a simpler and easier system which can be readily used by a minimum number of personnel when fabricating remote VTOL landing sites.

- Studies should be conducted to determine the required size of landing sites for typical jet VTOL aircraft. The operational suitability of typical sites should be evaluated on a cost effectiveness basis for typical VTOL jet aircraft.

- Additional flight testing is required to further evaluate the effectiveness of various sizes and densities of VTOL landing sites and to determine the effects of flight operational techniques on site design parameters.

- Further study and test to determine the required strength of landing site materials to resist wheel loads of VTOL aircraft and ground vehicles on various types of terrain are required due to the lack of data and a reliable analytical method.

- Design studies of light weight airborne material application systems predicated on an optimized material system and an improved catalyzing methods should be conducted.

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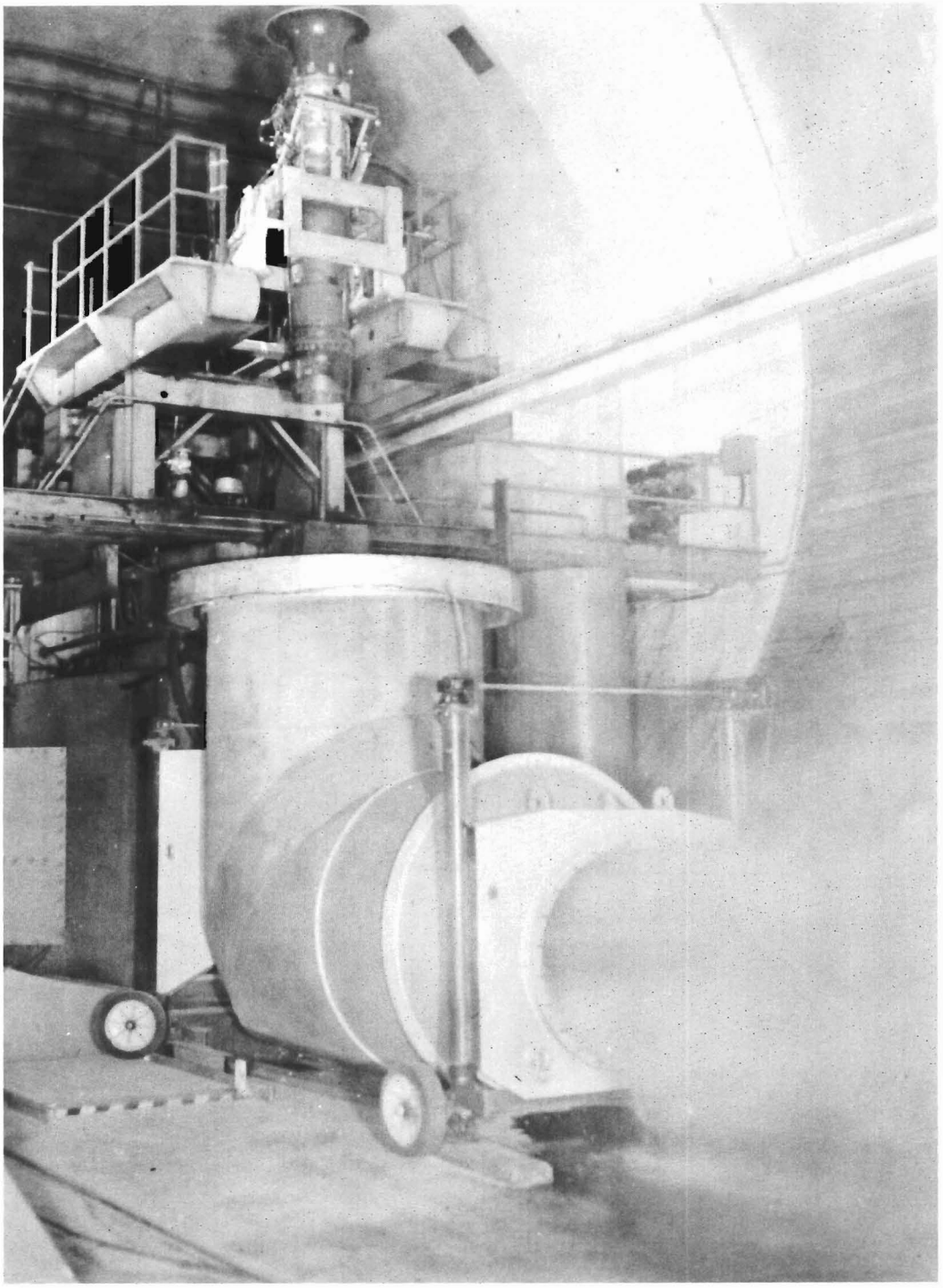


Figure 1 RTD Jet Test Facility

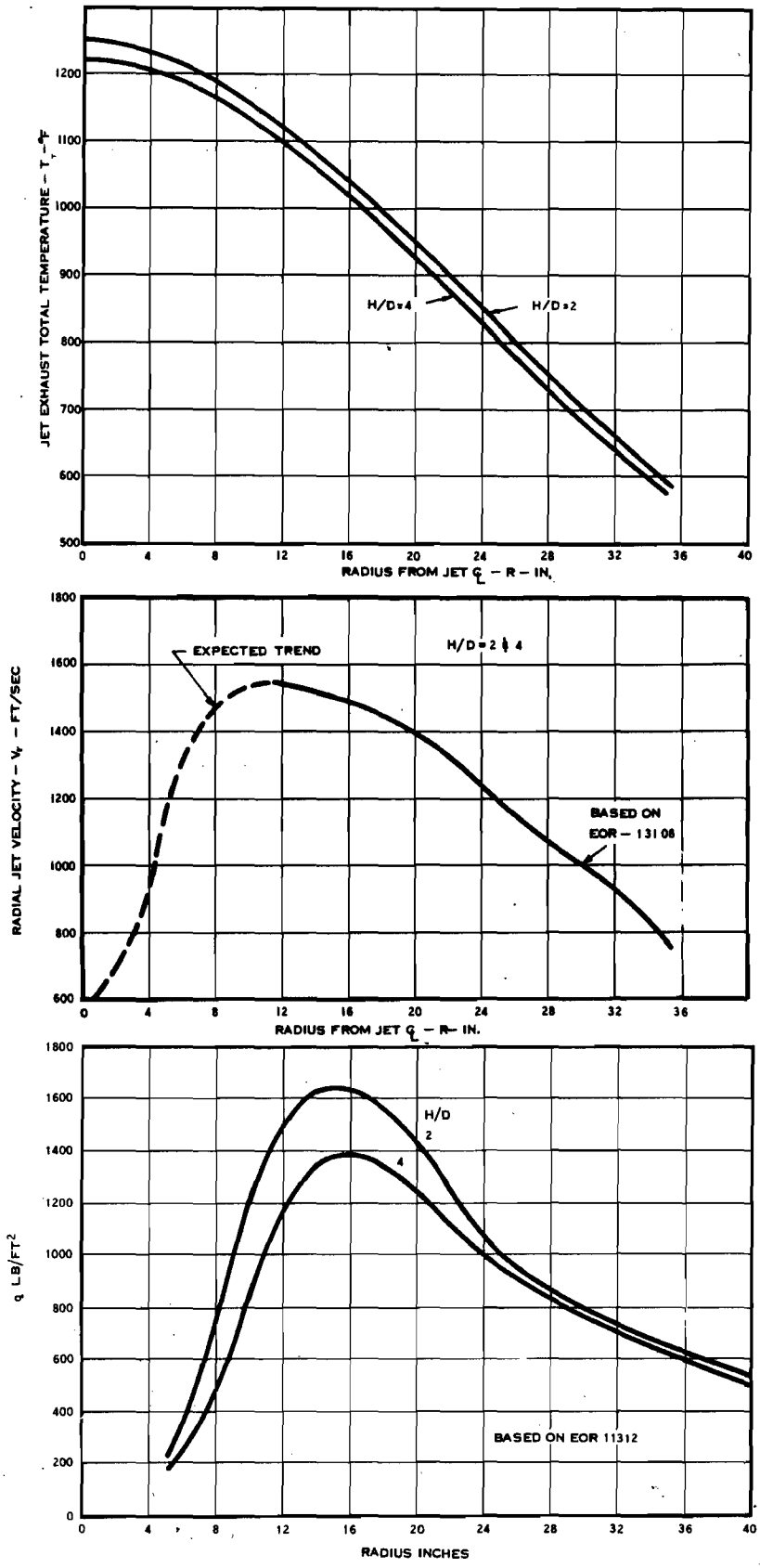


Figure 2 Ground Level Exhaust Gas Temperature - Velocity - Dynamic Pressure vs Radius From Jet Centerline - J85-GE-5 Engine - Military Power

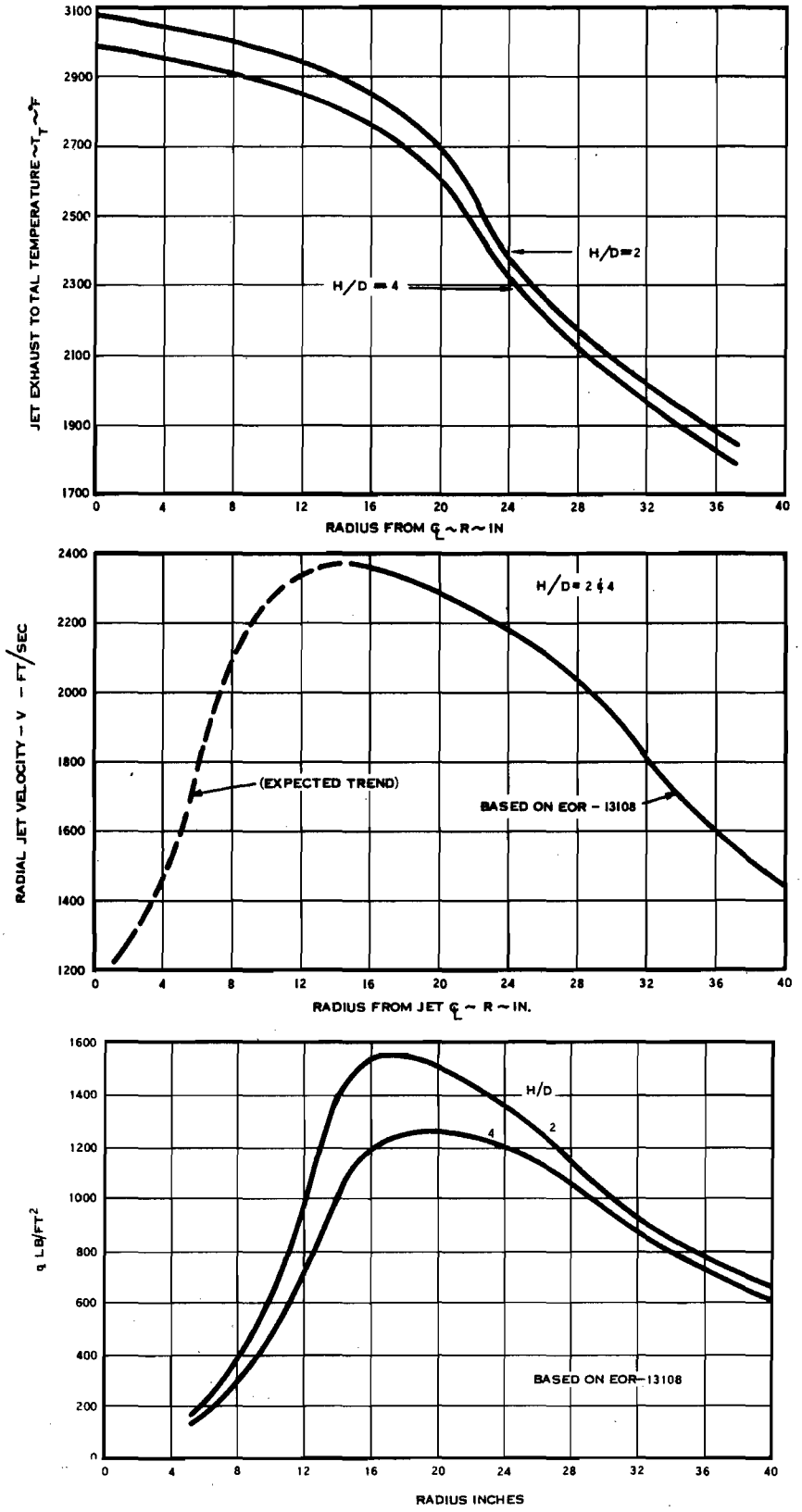
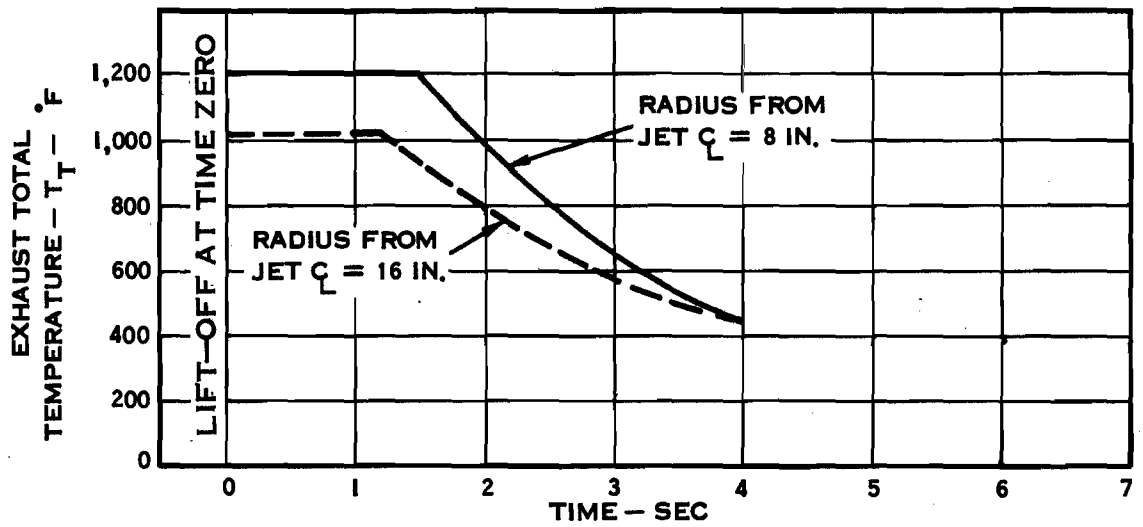


Figure 3 Ground Level Exhaust Gas Temperature - Velocity - Dynamic Pressure vs Radius From Jet Centerline - J85-GE-5 Engine - Afterburner



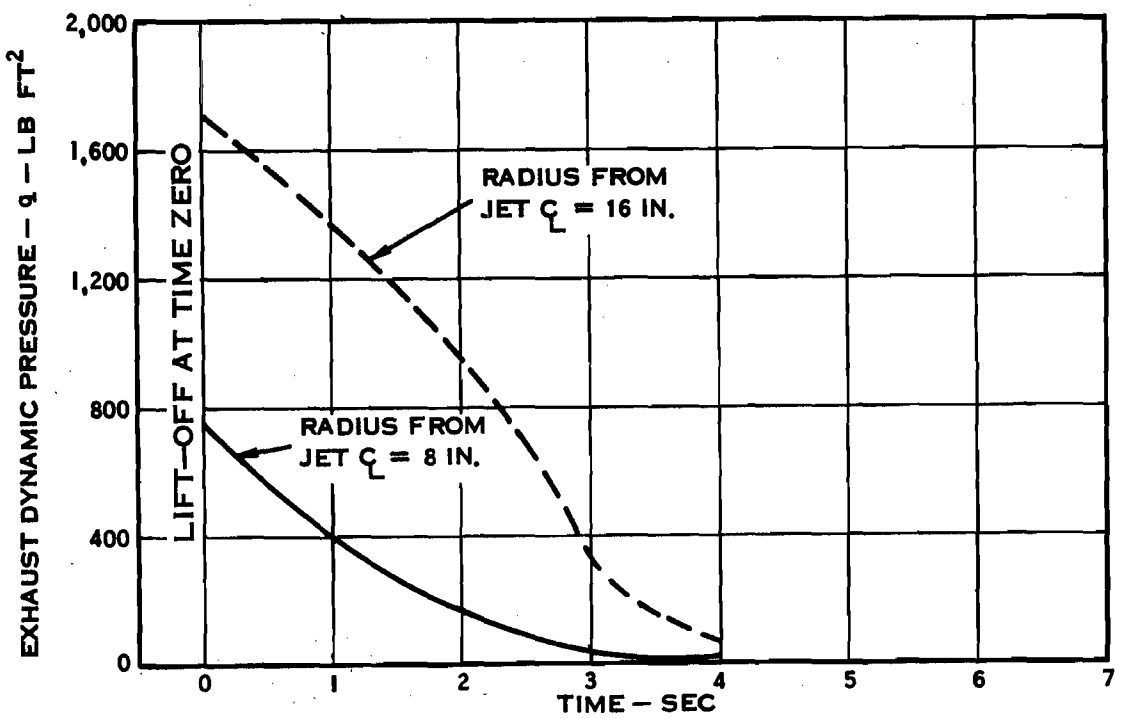
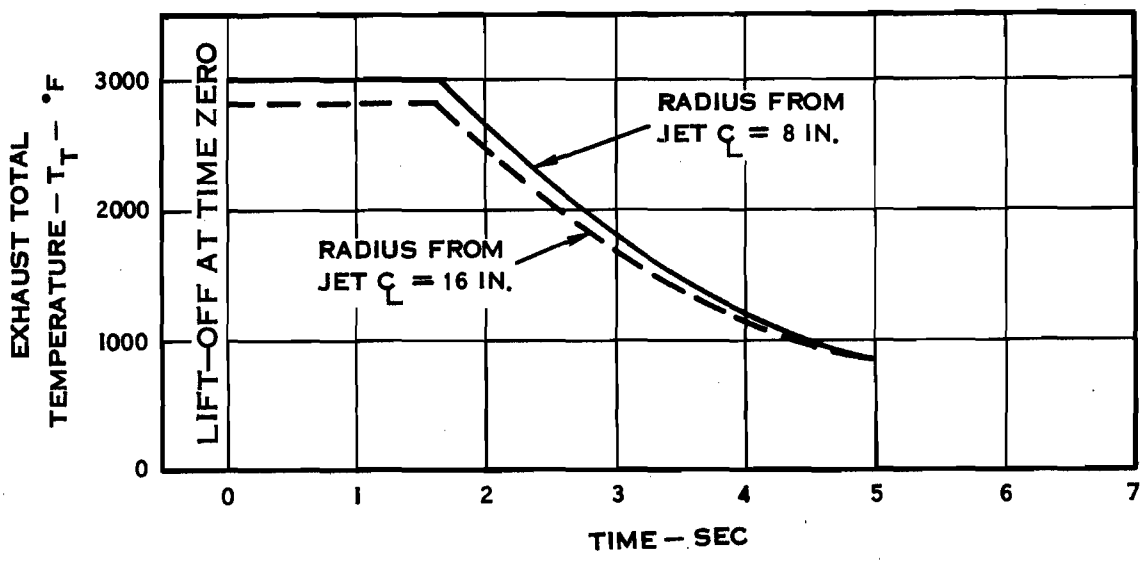


Figure 4 Ground Level Exhaust Gas Temperature and Dynamic Pressure vs Time for a 1.05 T/W Vertical Takeoff – J85-GE-5 Engine - Military Power



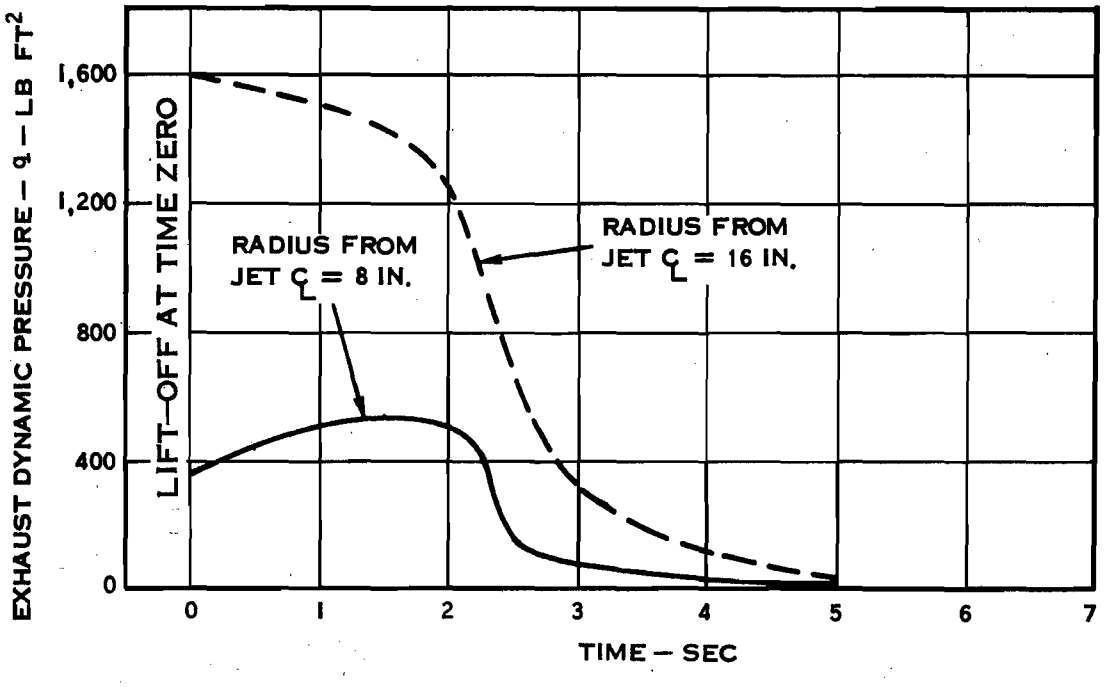
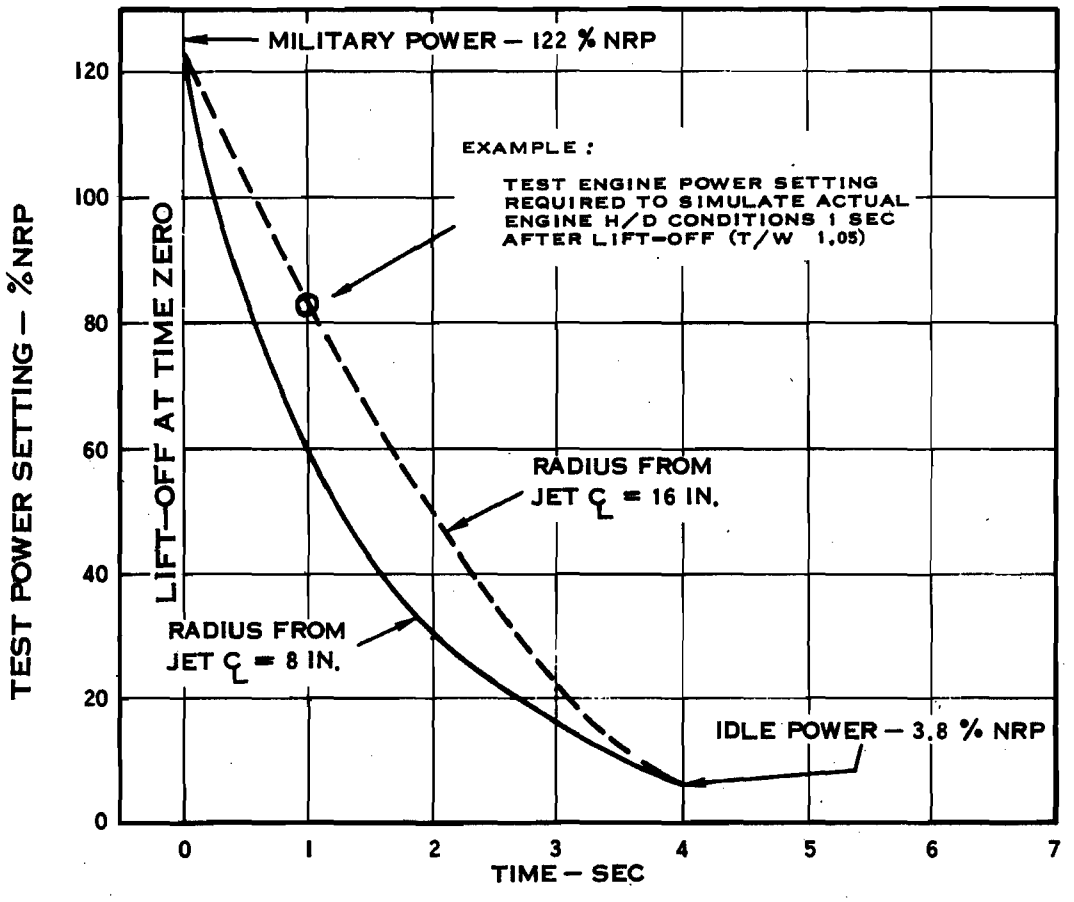


Figure 5 – Ground Level Exhaust Gas Temperature and Dynamic Pressure vs Time for a 1.05 T/W Vertical Takeoff – J85-GE-5 – Afterburner



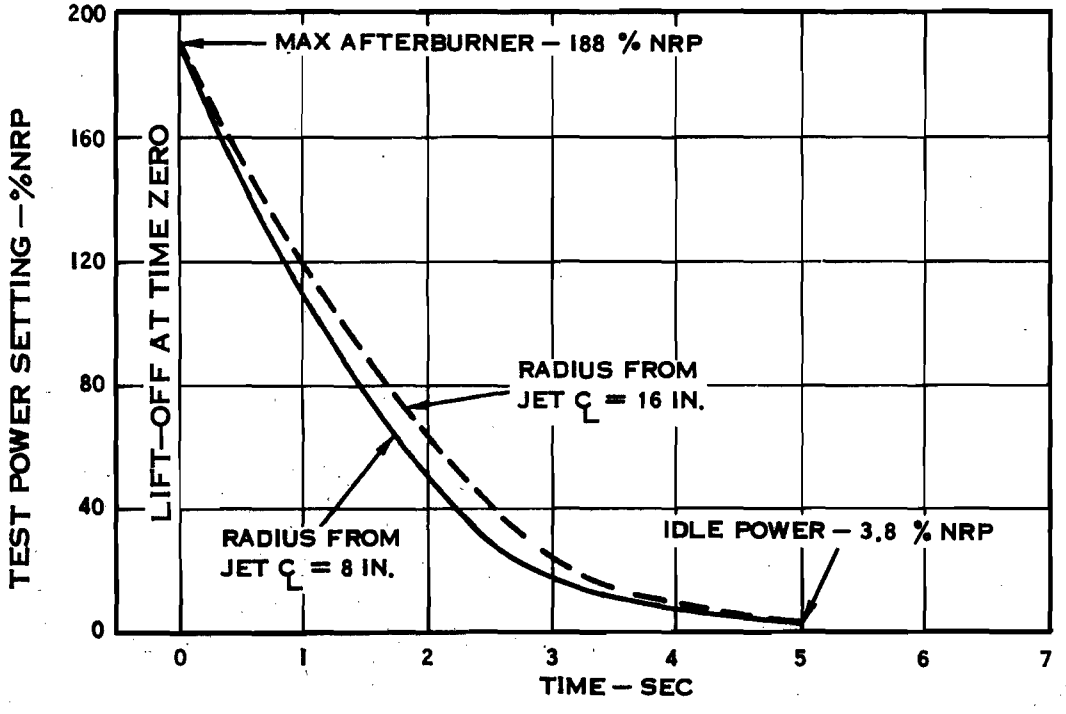


Figure 6 Engine Power Setting vs Time for Simulating Ground Downwash During a 1.05 T/W Vertical Takeoff - J85-GE-5 Engine at H/D 2

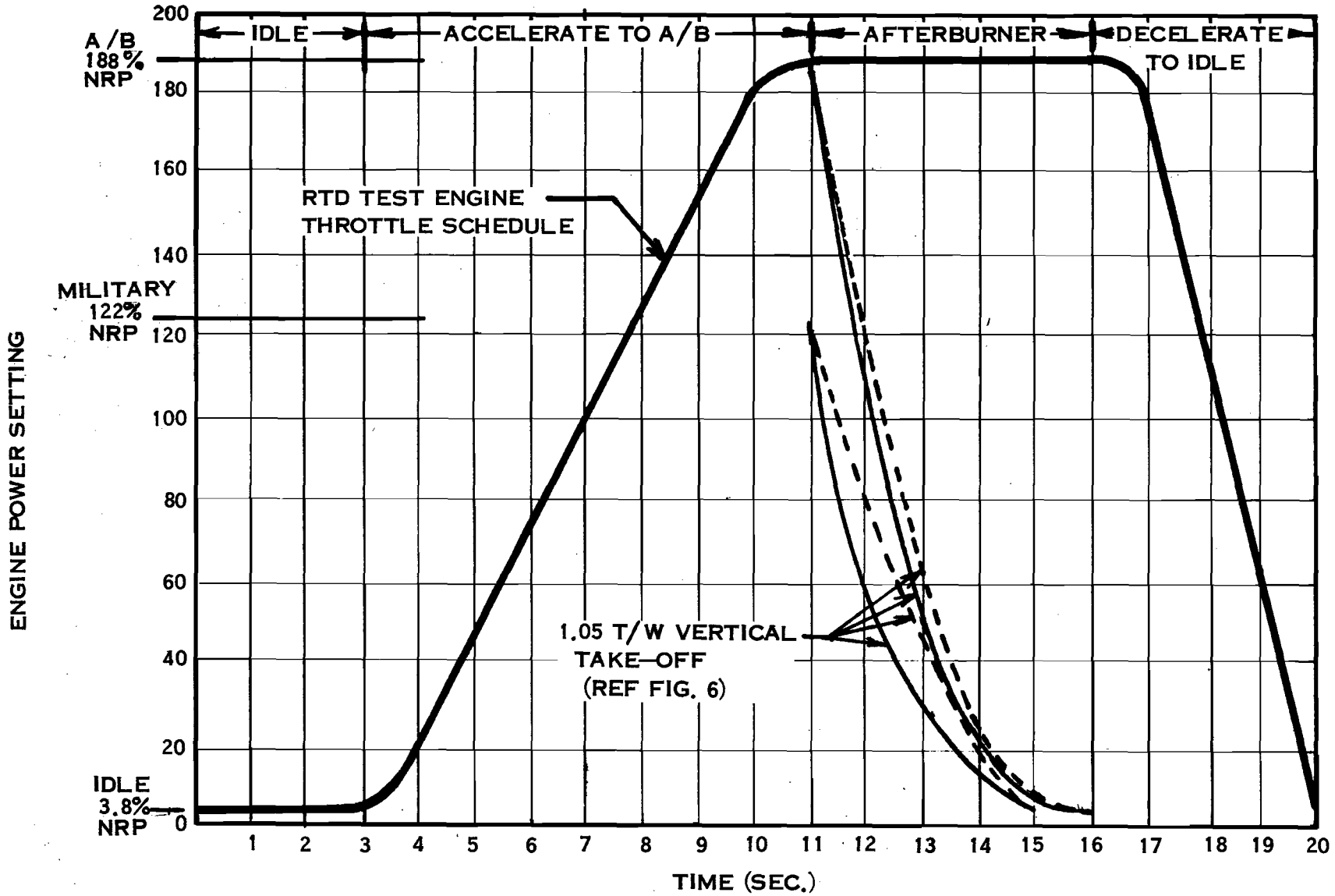
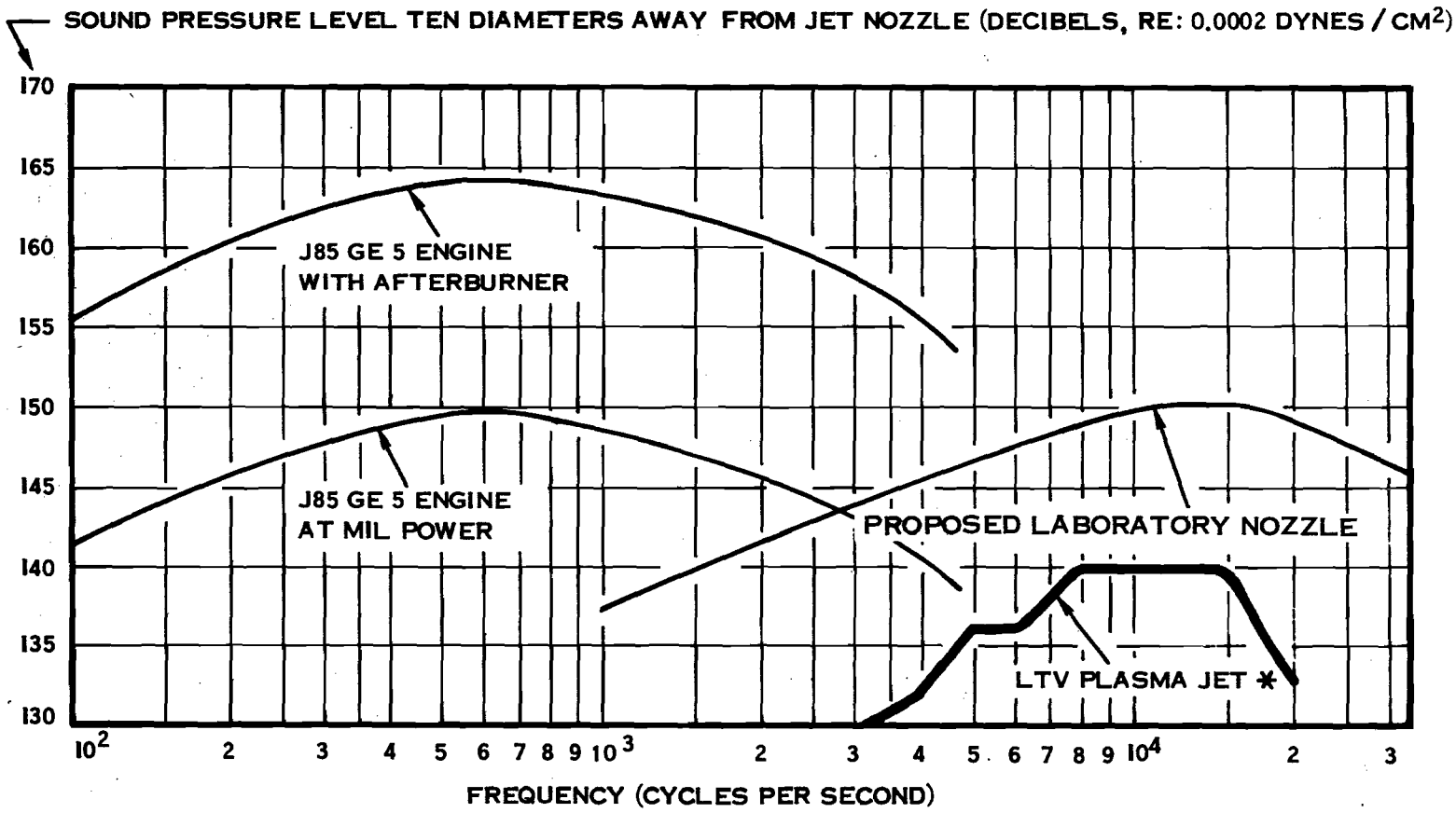


Figure 7 Actual Engine Power vs Time for RTD Jet Engine Facility Tests (9 Ft Dia. Specimens)



PROPOSED LAB NOZZLE
DIAMETER=1.13 IN.

EXIT VELOCITY 1,700 FT SEC

J85 GE 5 ENGINE NOZZLE
DIAMETER = 20 IN.

EXIT VELOCITY = 1880 FT / SEC (MIL POWER)
=2890 FT / SEC (AFTERBURNER)

* MEASURED LEVEL CORRECTED TO SAMPLE POSITION

Figure 8 Sound Pressure Level Spectra

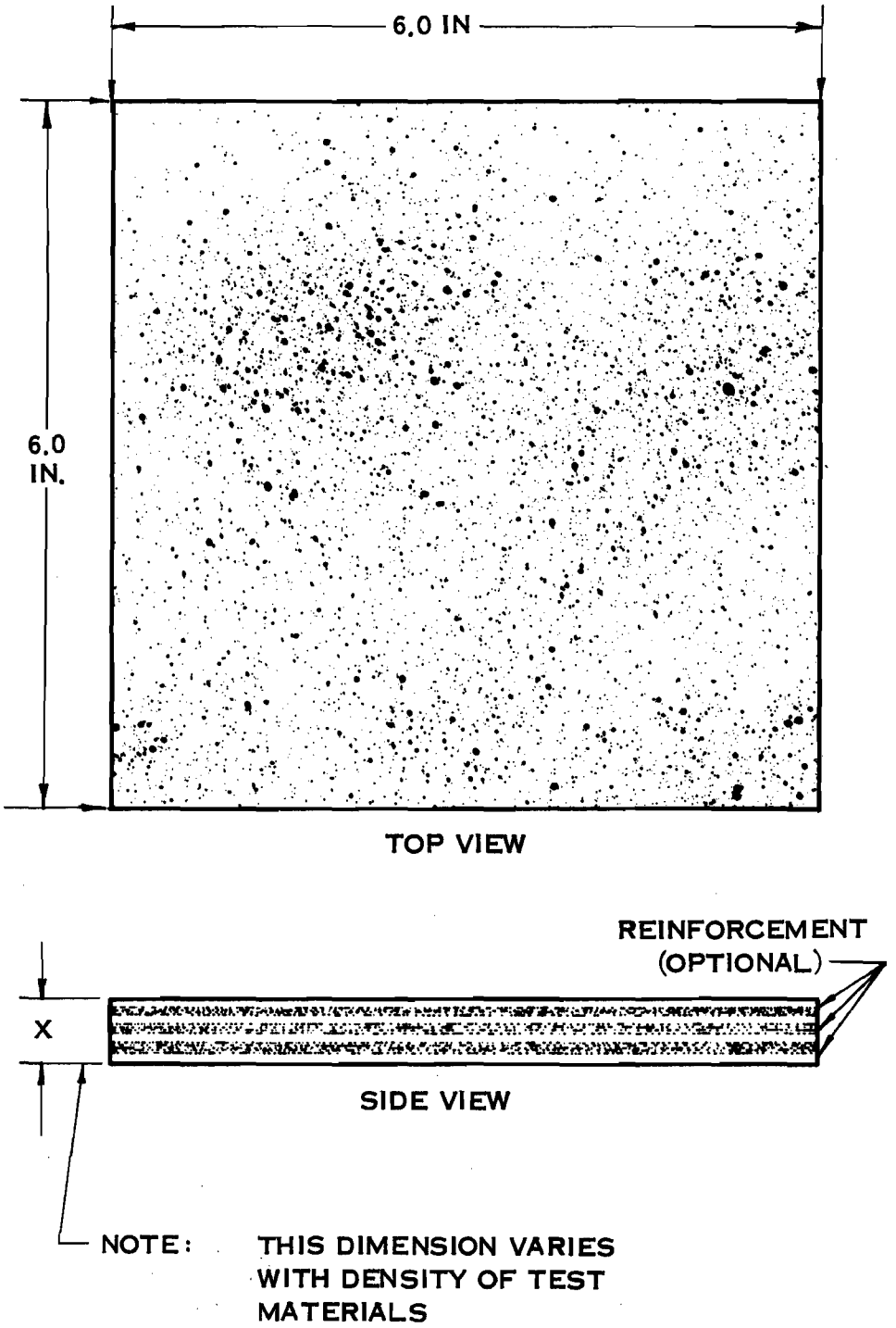


Figure 9 Torch Test Specimen

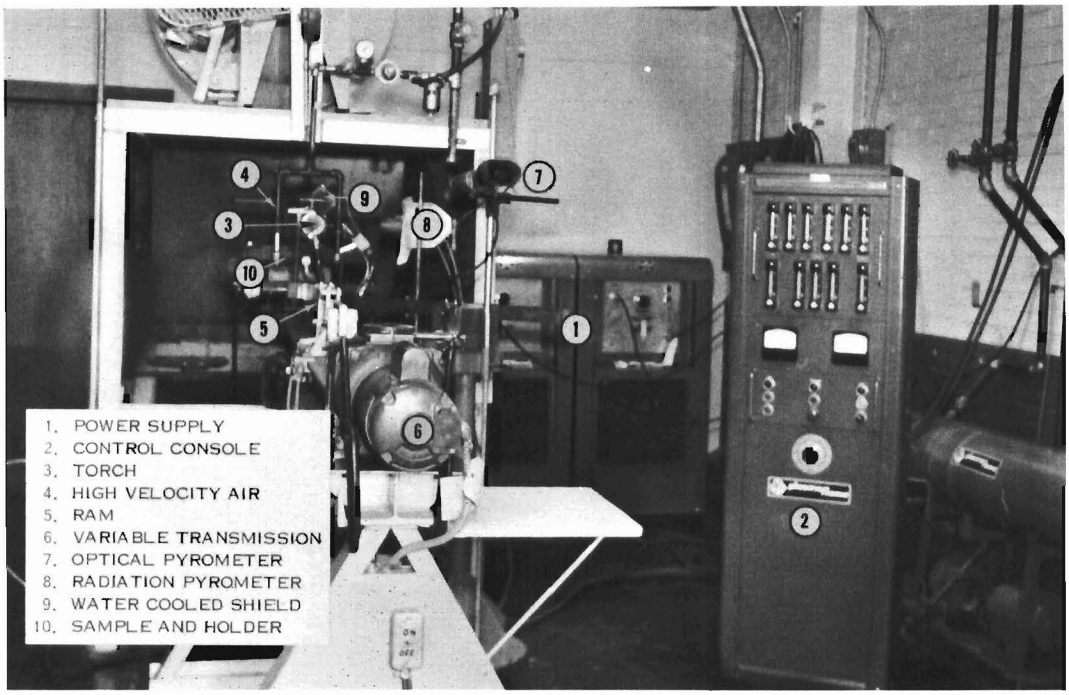


Figure 10 Plasma-Arc Test Facility

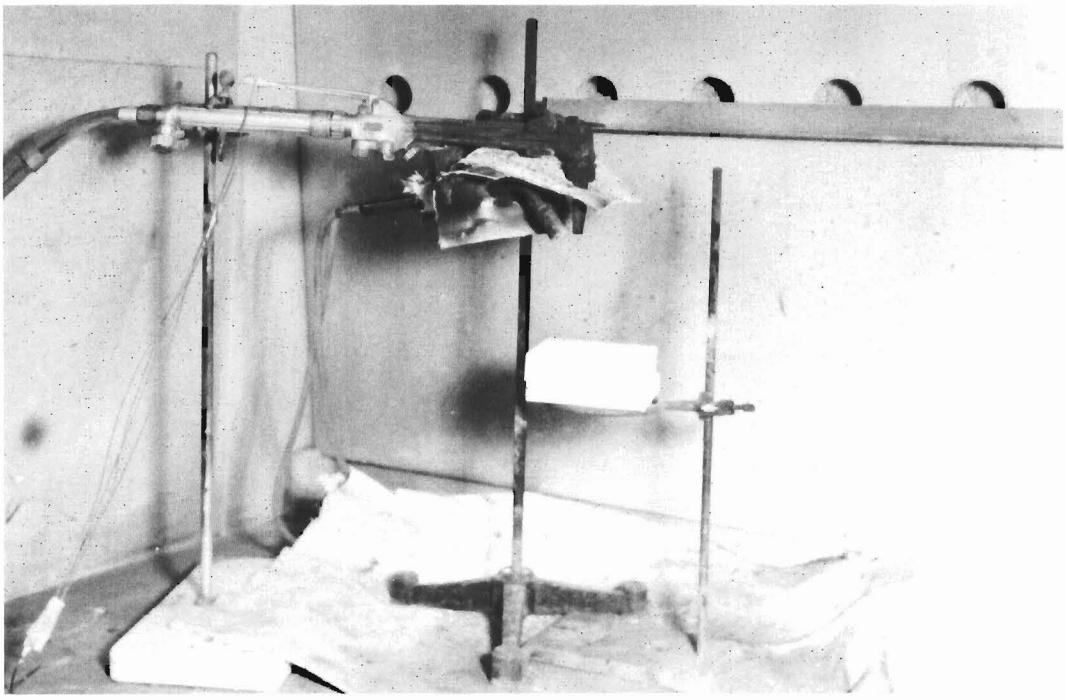


Figure 11 Oxyacetylene Cutting Torch Set-up for Flame Erosion Tests

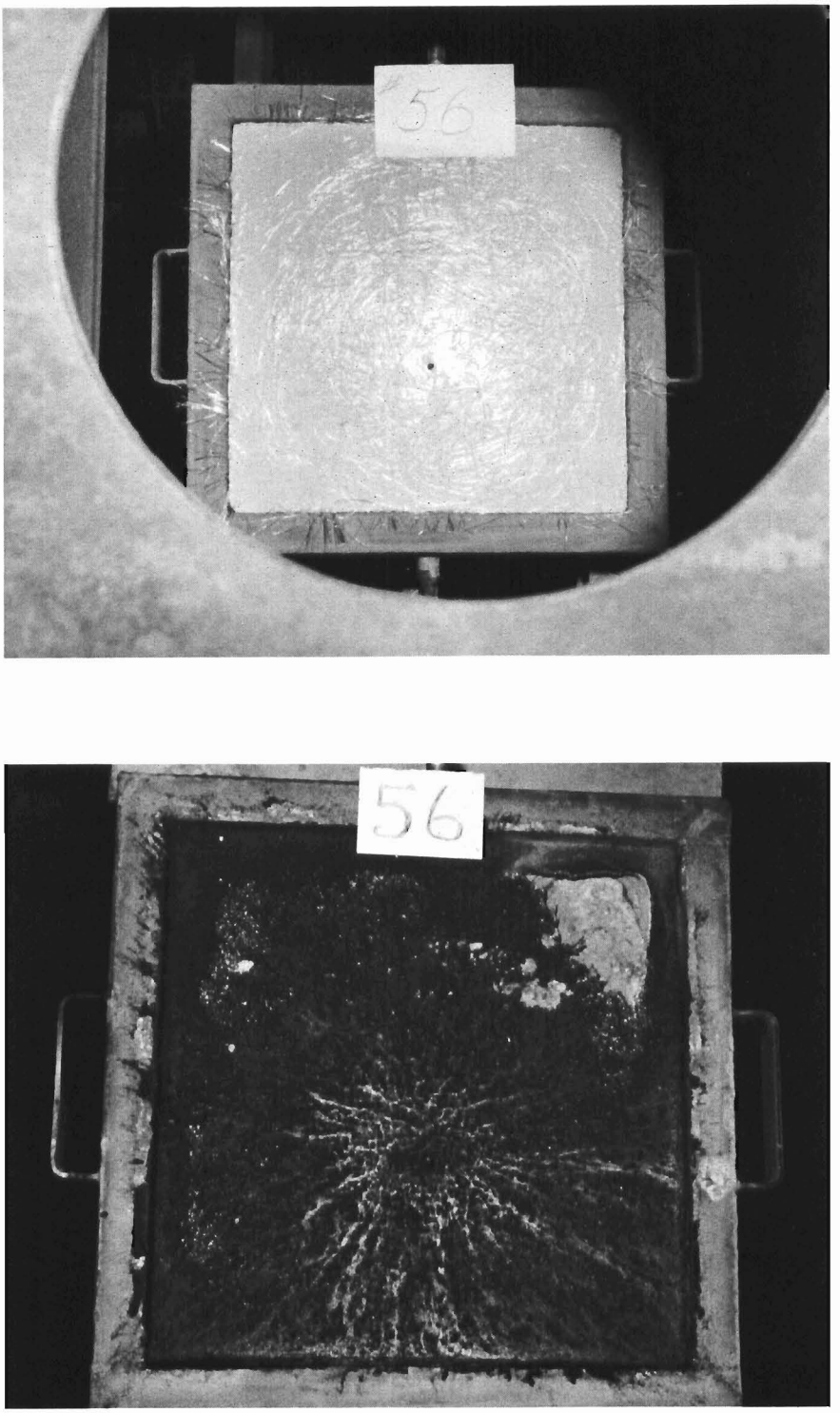


Figure 12 Typical 2 Ft x 2 Ft RTD Jet Engine Test Specimen (Filled Polyester and Fiberglass Before and After Exposure)

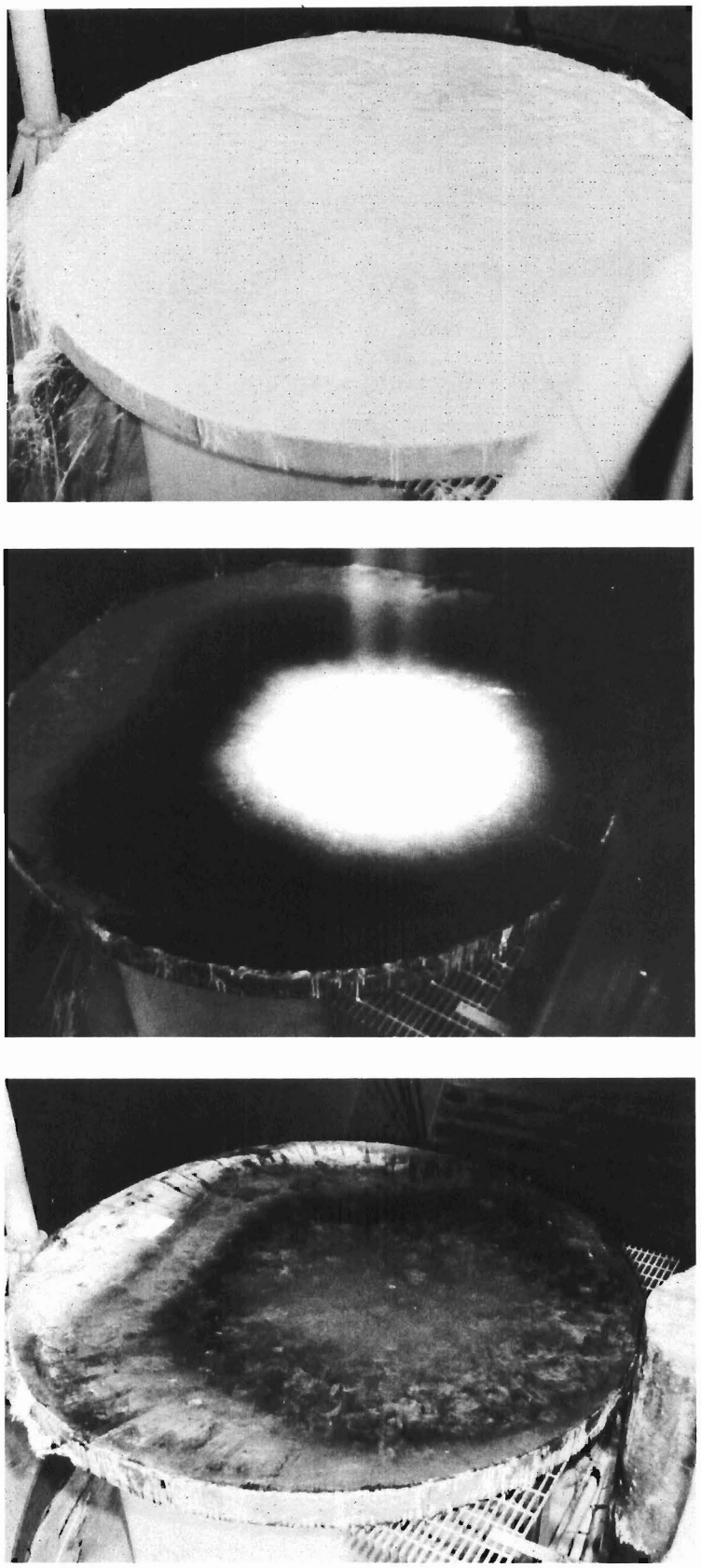


Figure 13 Typical 9-Ft Diameter RTD Jet Engine Test Specimen (Filled Polyester and Fiberglass Before, During, and After Exposure)

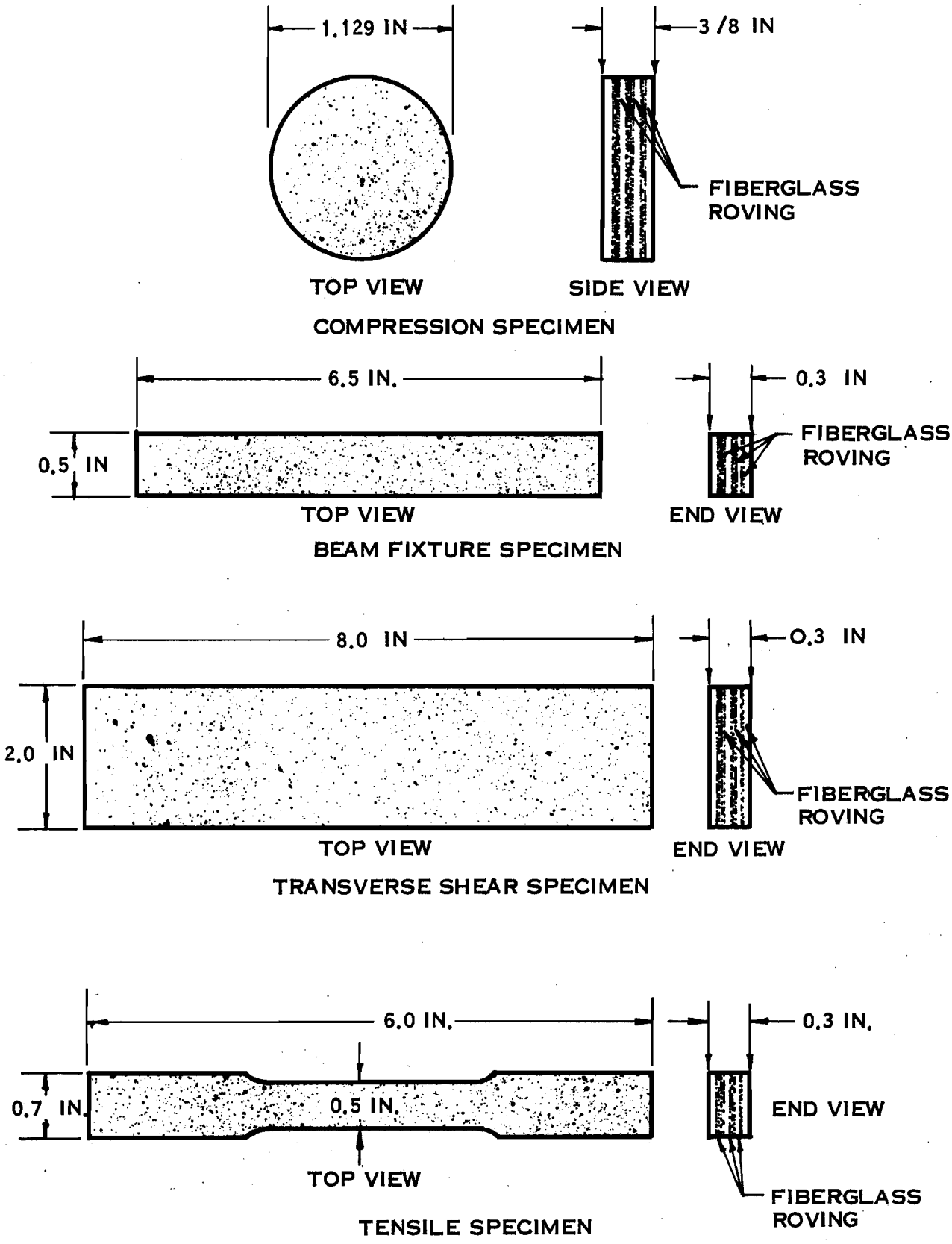


Figure 14 Mechanical Properties Test Specimens

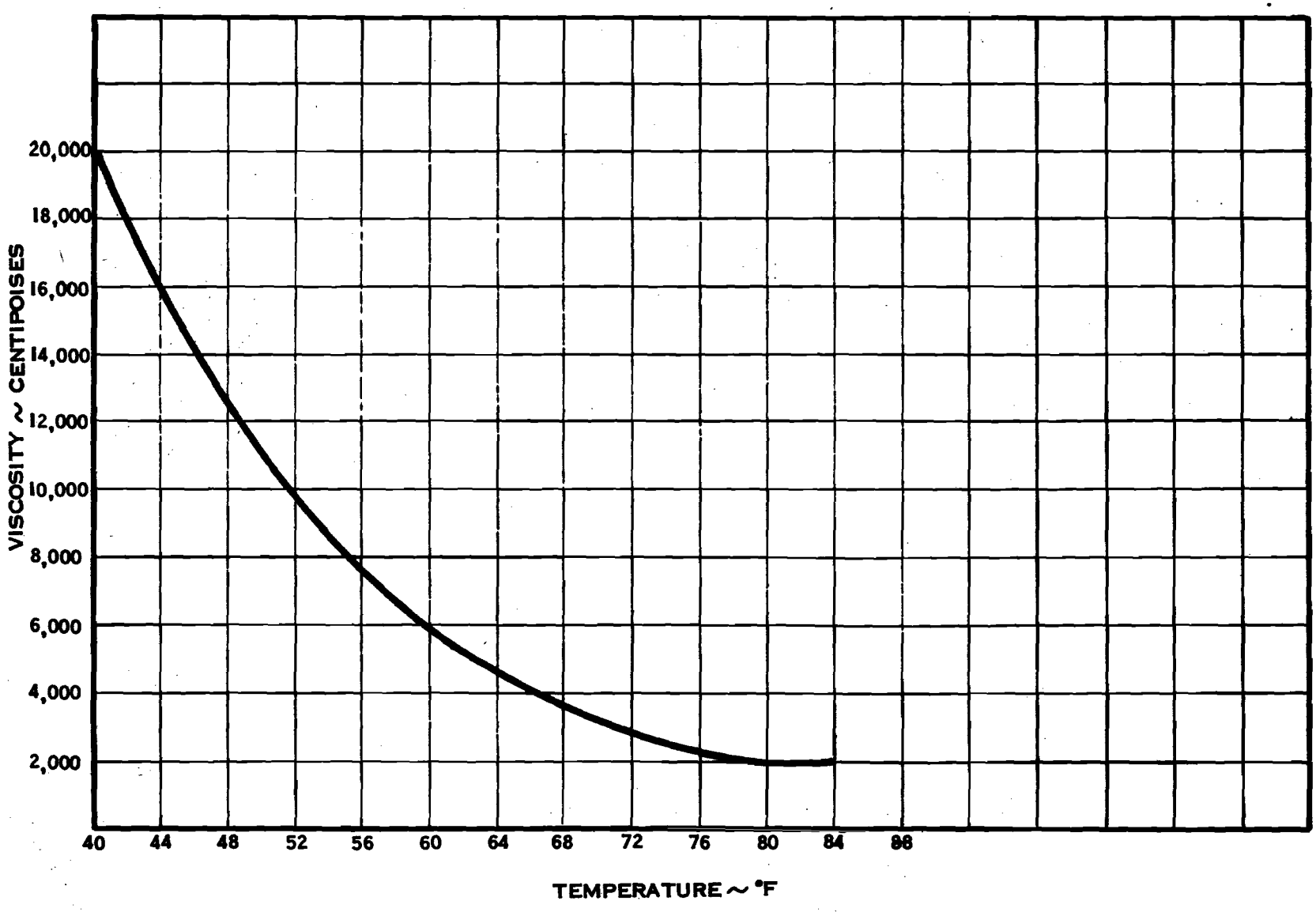


Figure 15 Viscosity of Uncatalyzed Formula A Resin System vs Temperature

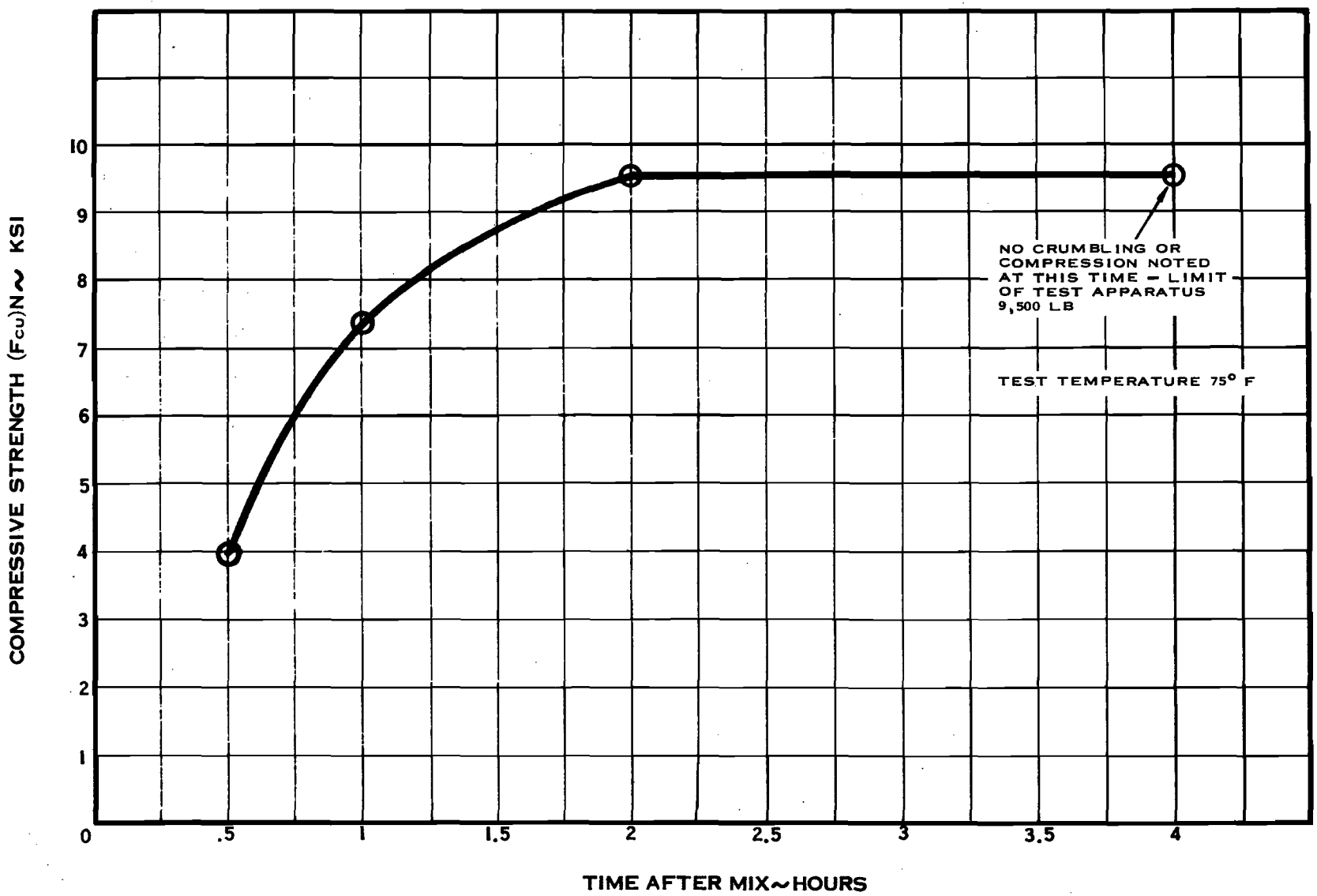


Figure 16 Compressive Strength of Formula A Resin System vs Time

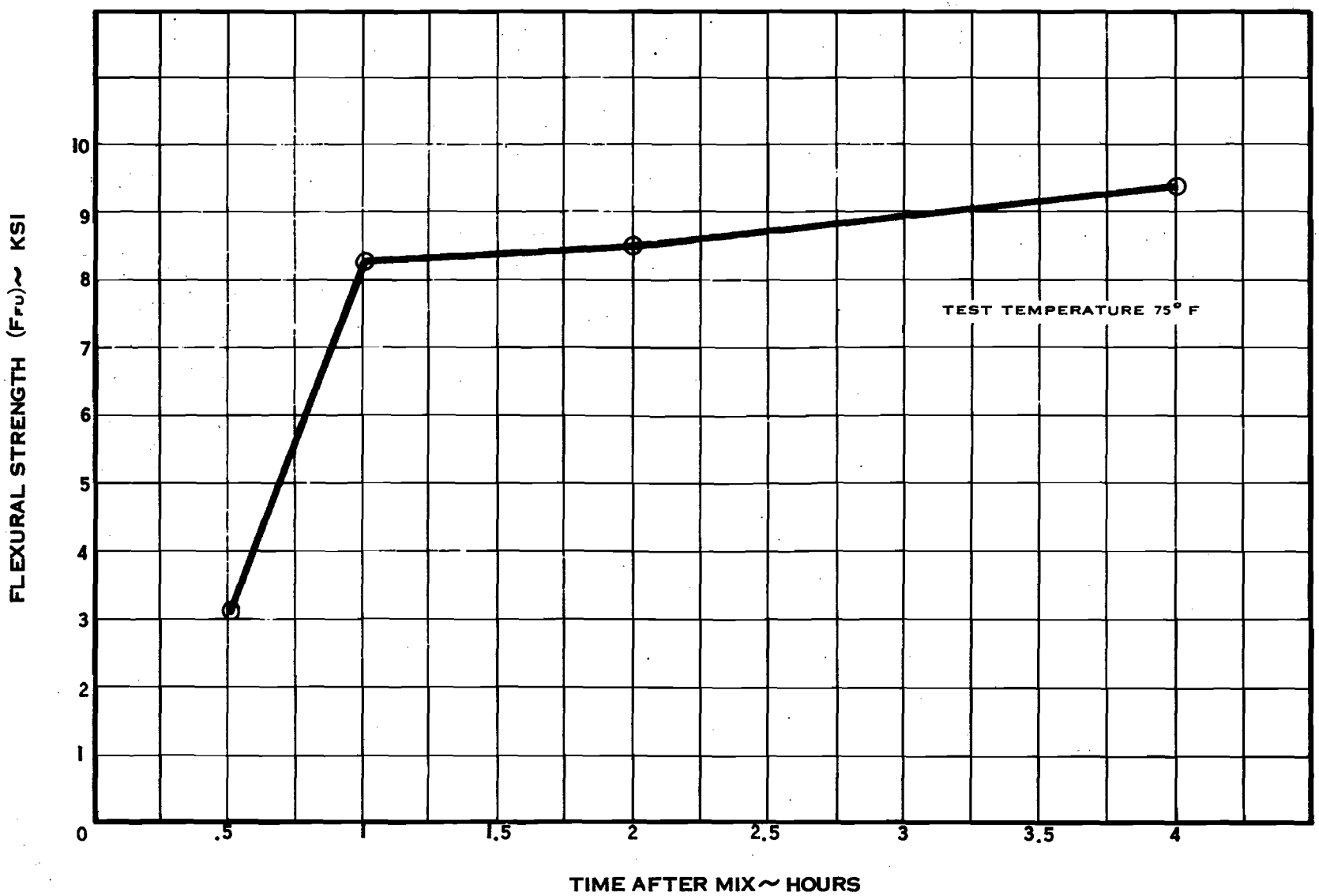


Figure 17 Flexural Strength of Formula A Resin System vs Time

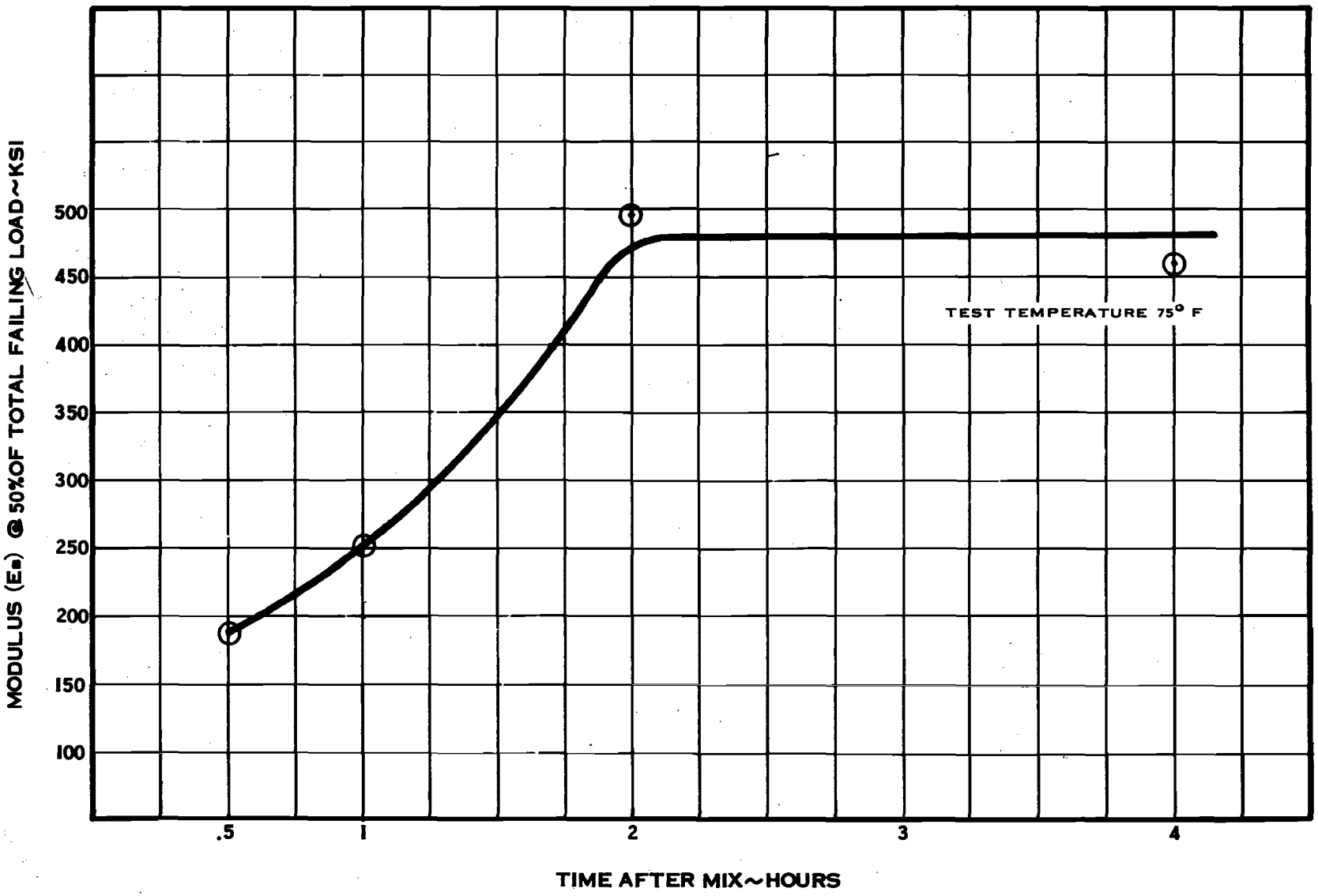


Figure 18 Flexural Modulus of Formula A Resin System vs Time

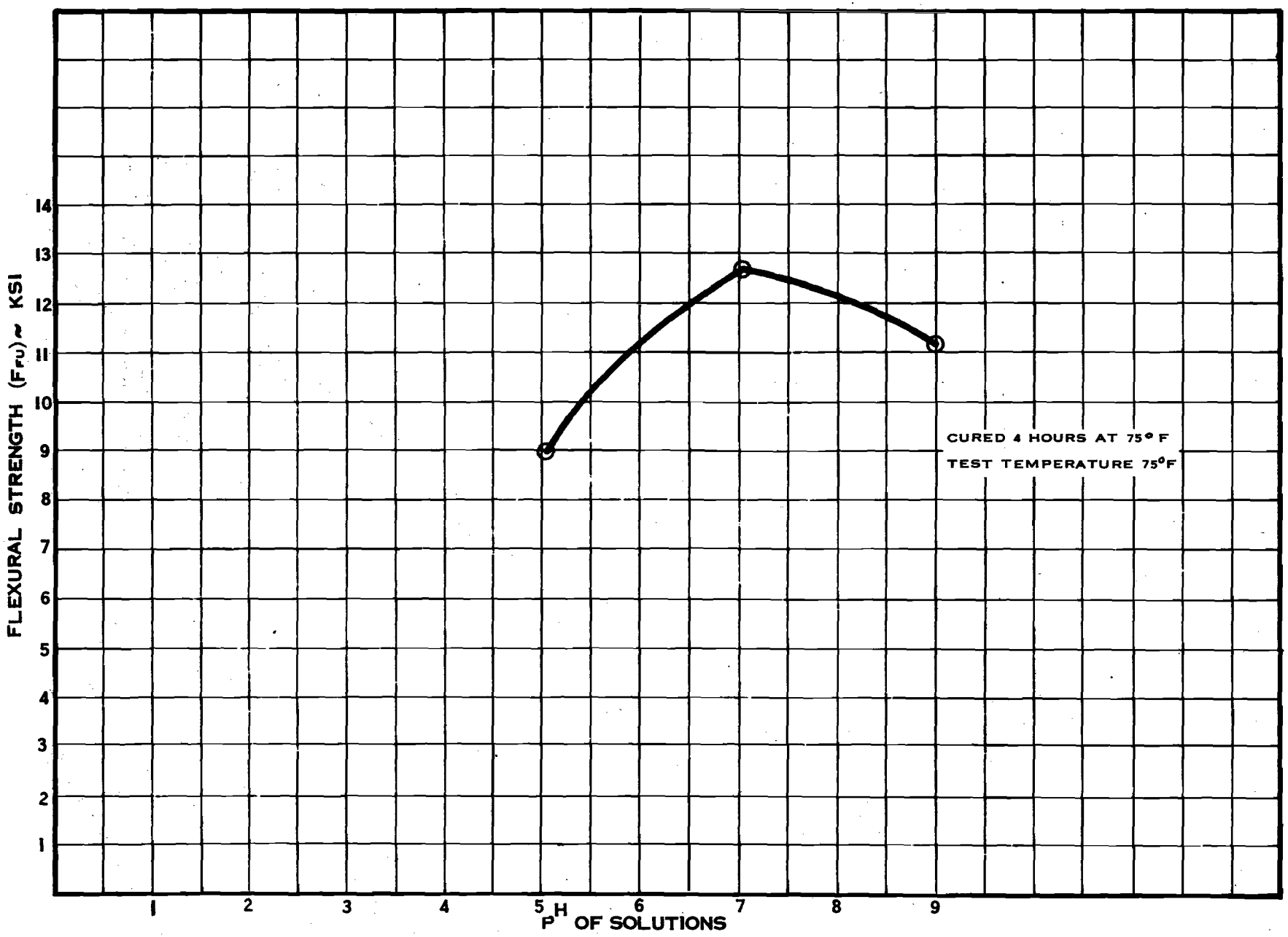


Figure 19 Effect of pH Solutions on Flexural Strength of Formula A Resin System

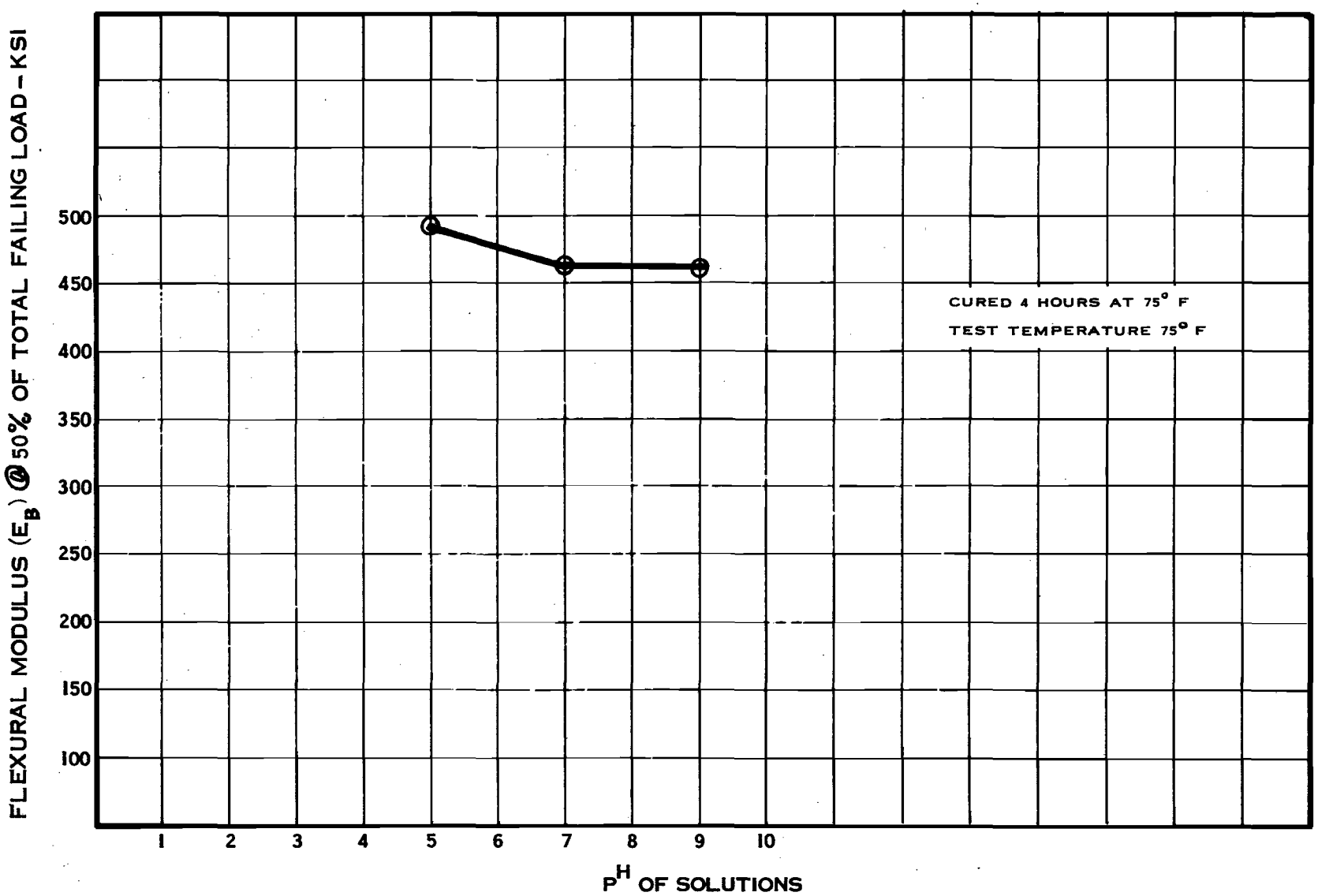


Figure 20 Effect of pH Solutions on Flexural Modulus of Formula A Resin System

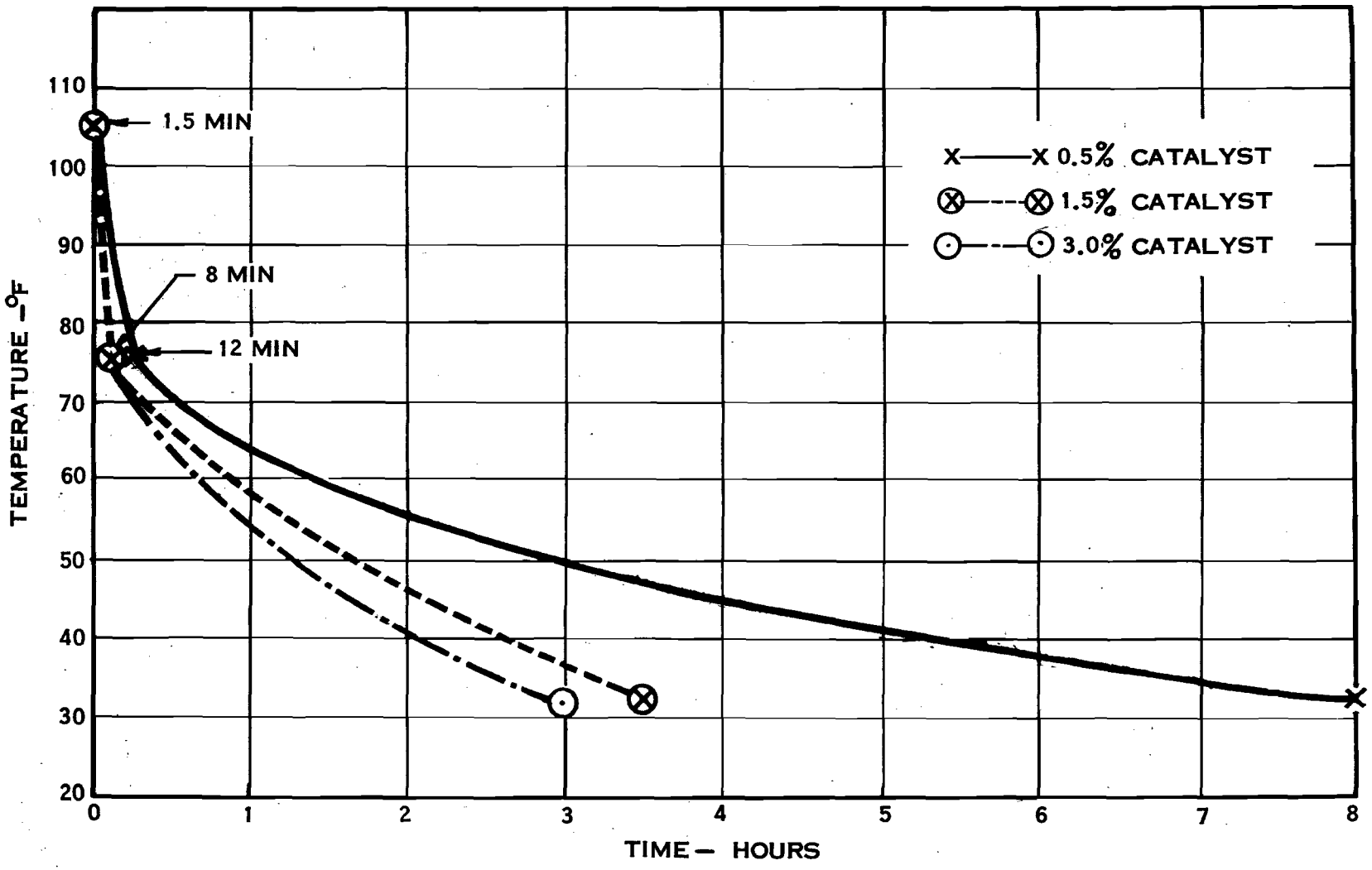


Figure 21 Effect of Catalyst Concentration and Temperature on Gel Time

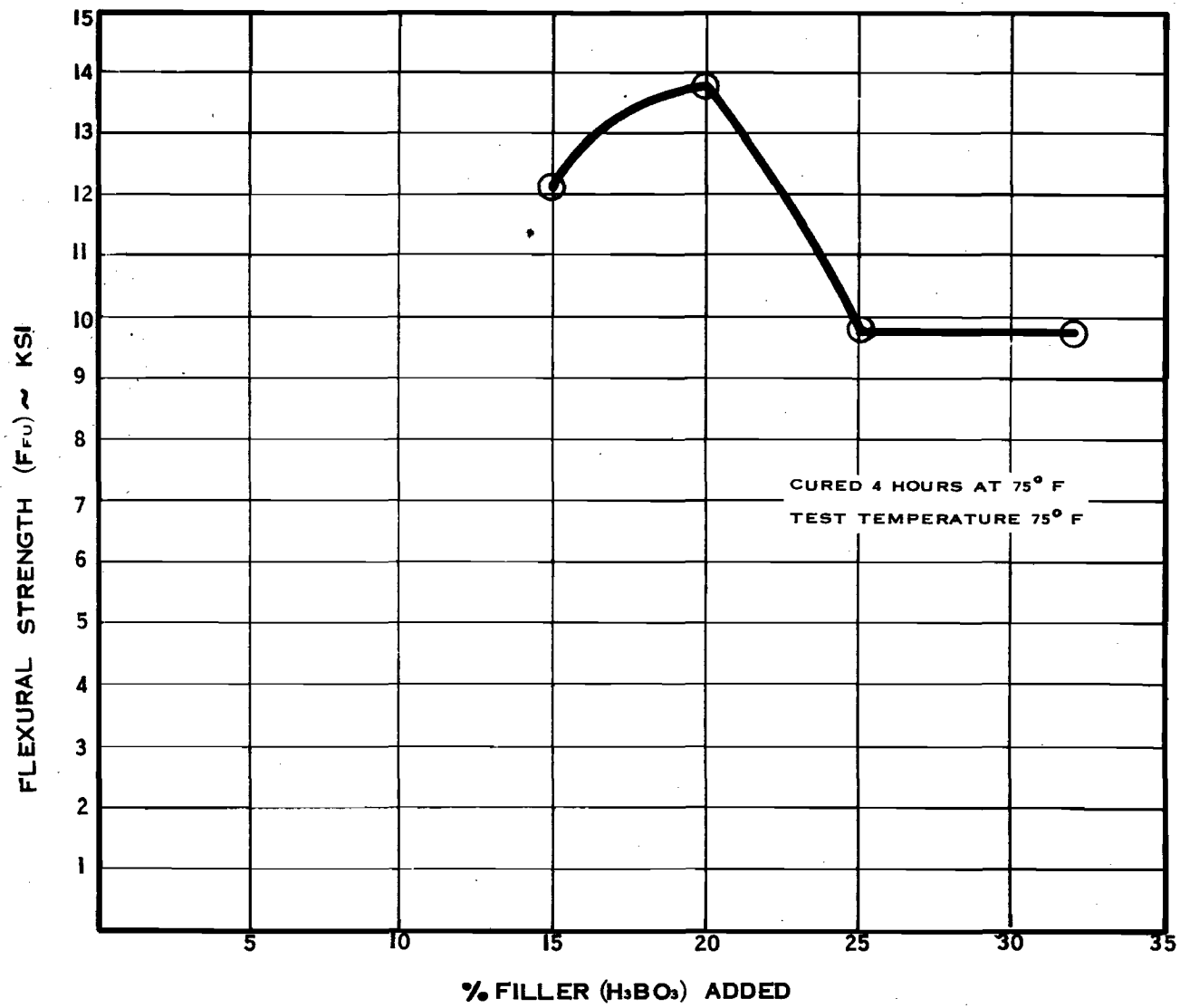


Figure 22 Flexural Strength vs % Filler (Modification of Formula A Resin System)

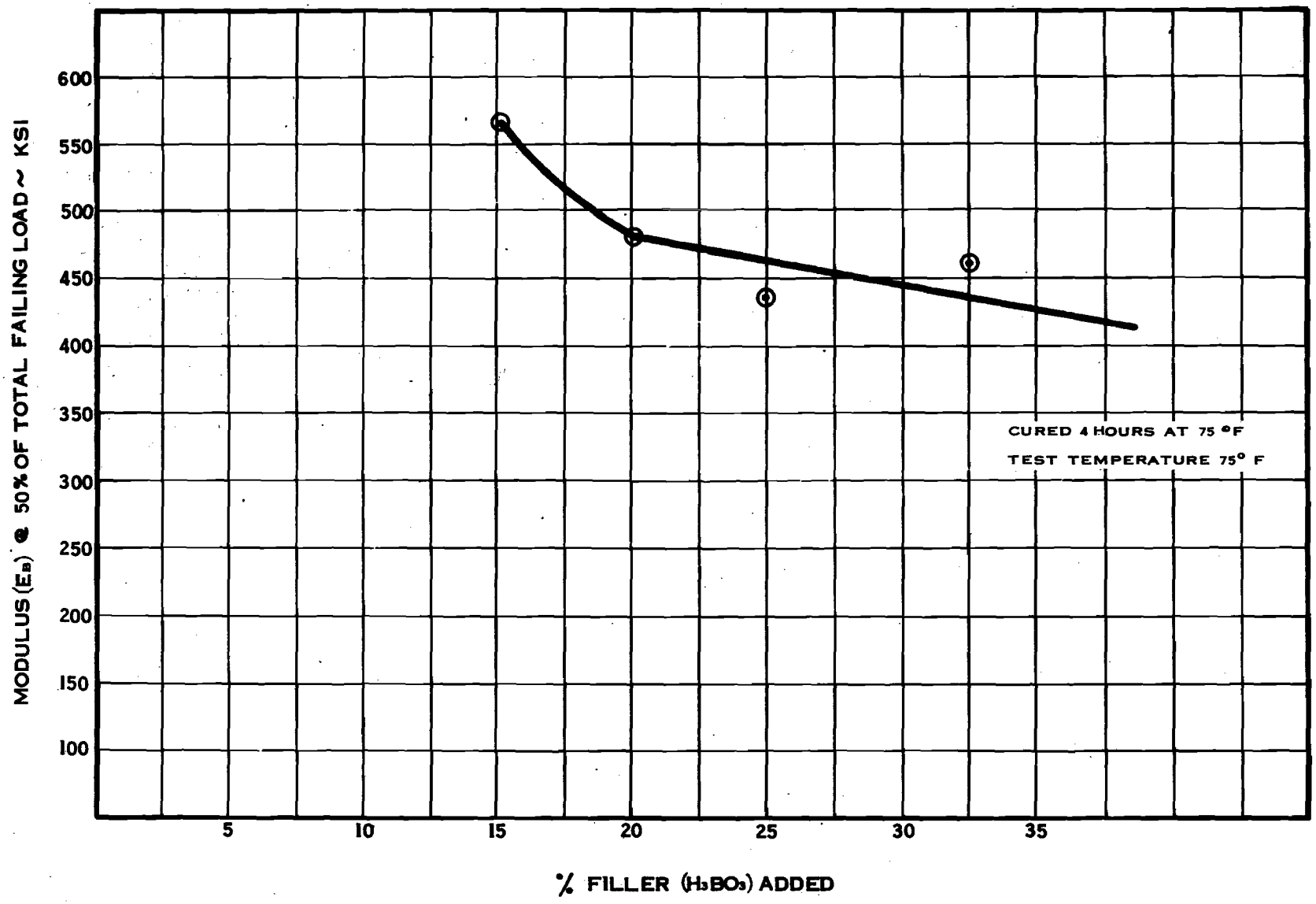


Figure 23 Flexural Modulus vs % Filler (Modification of Formula A Resin System)

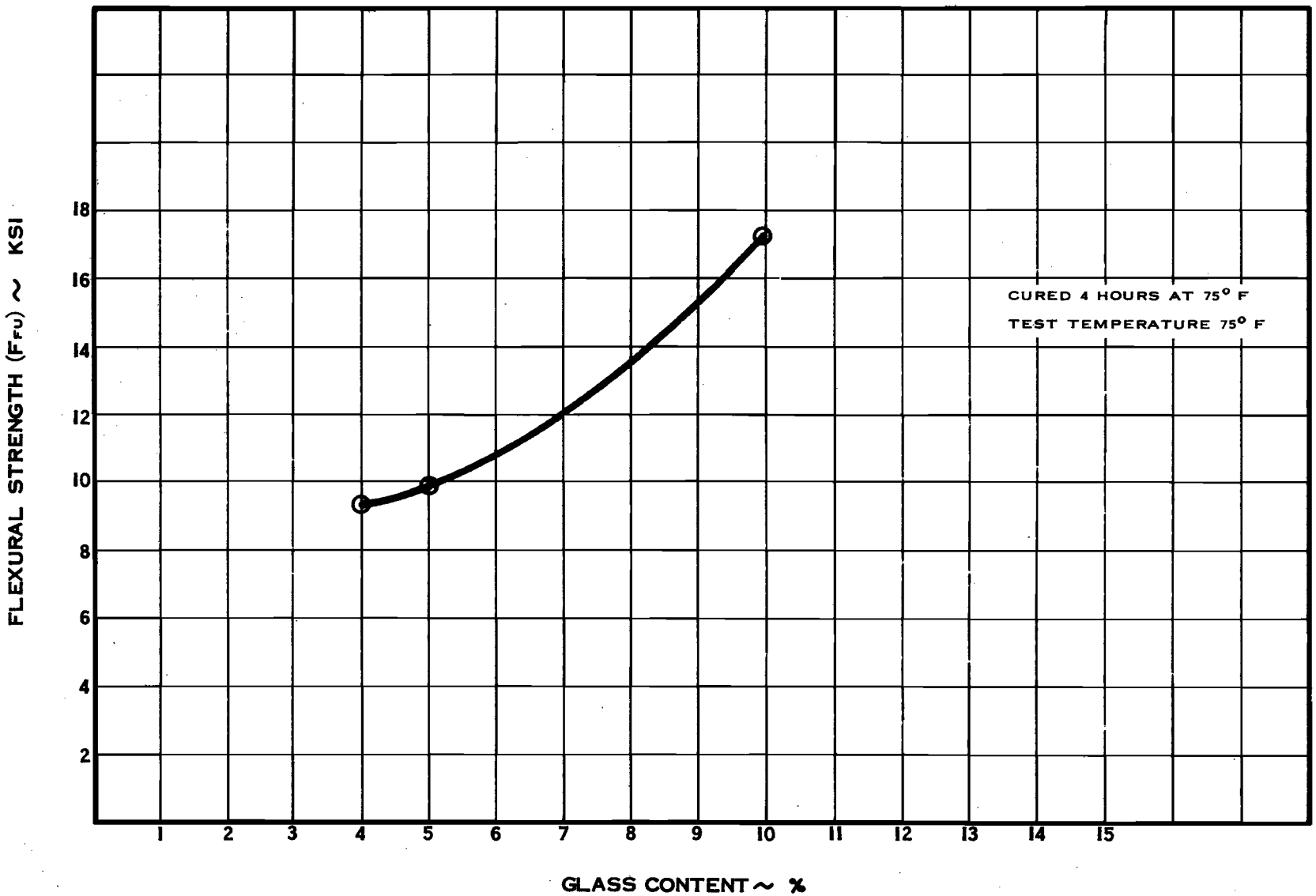


Figure 24 Flexural Strength vs % Fiberglass (Modification of Formula A Resin System)

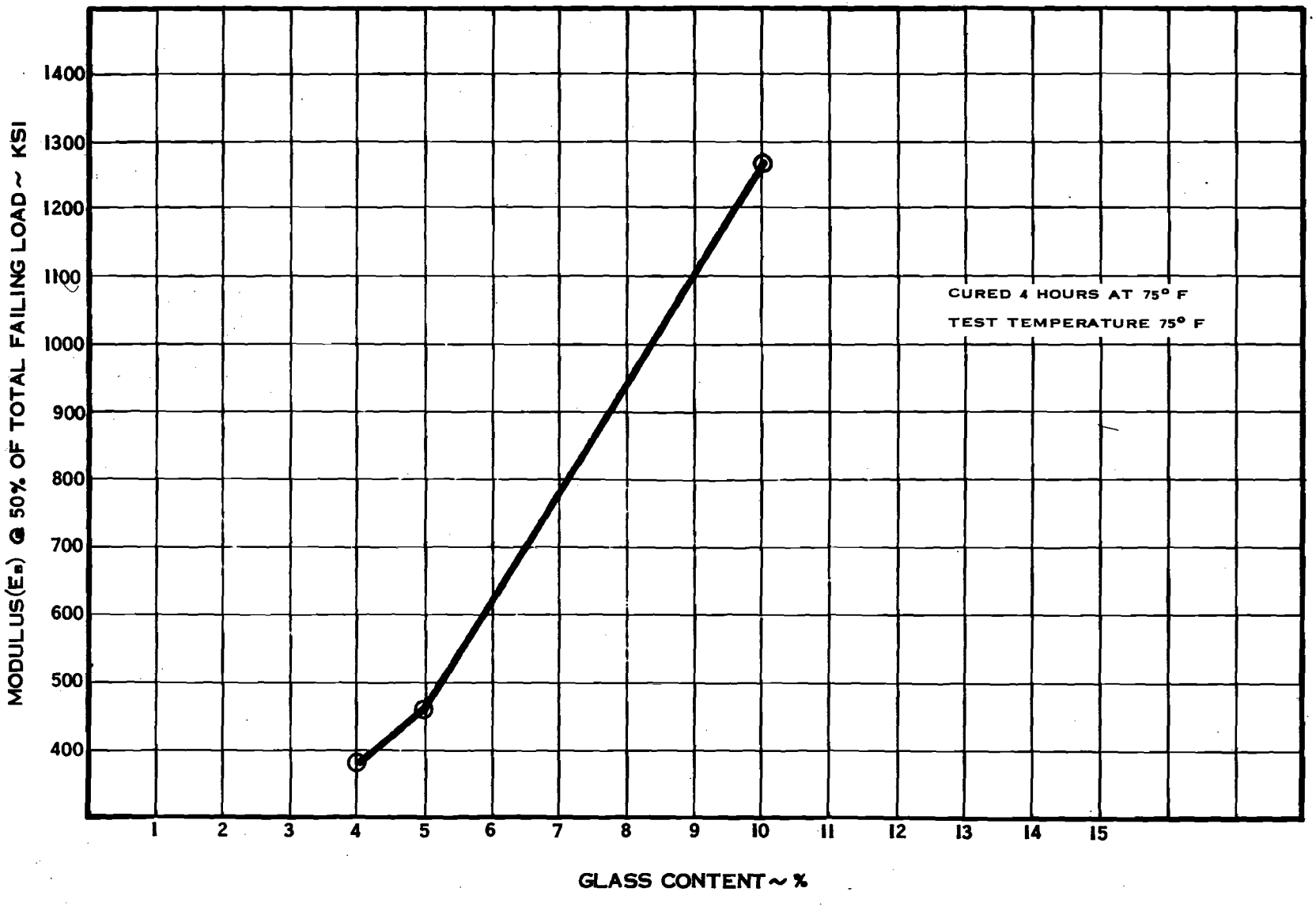


Figure 25 Flexural Modulus vs % Fiberglass (Modification of Formula A Resin System)

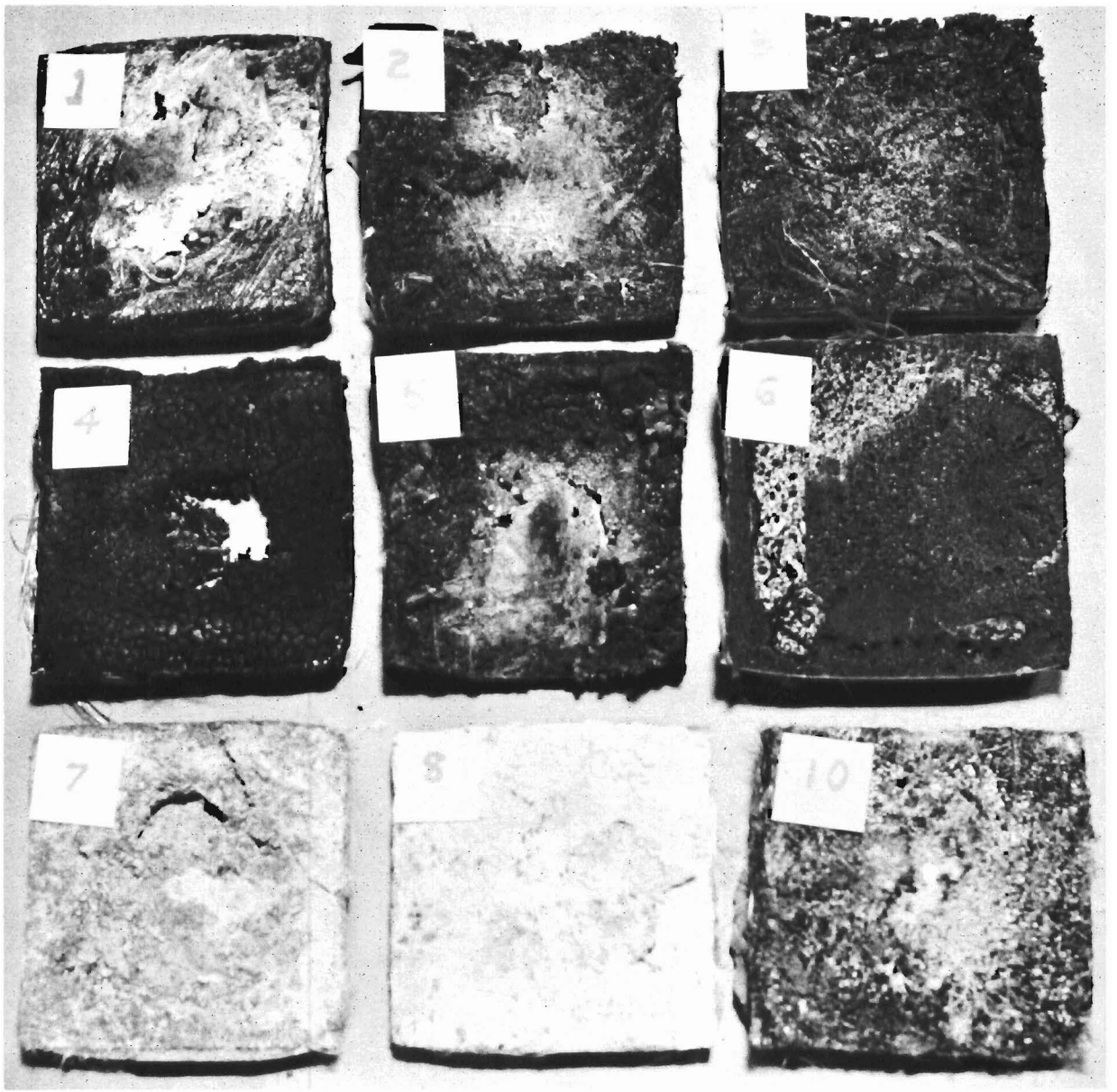


Figure 26 Flame Erosion Screening Test Specimens After Exposure (Tested to Failure)

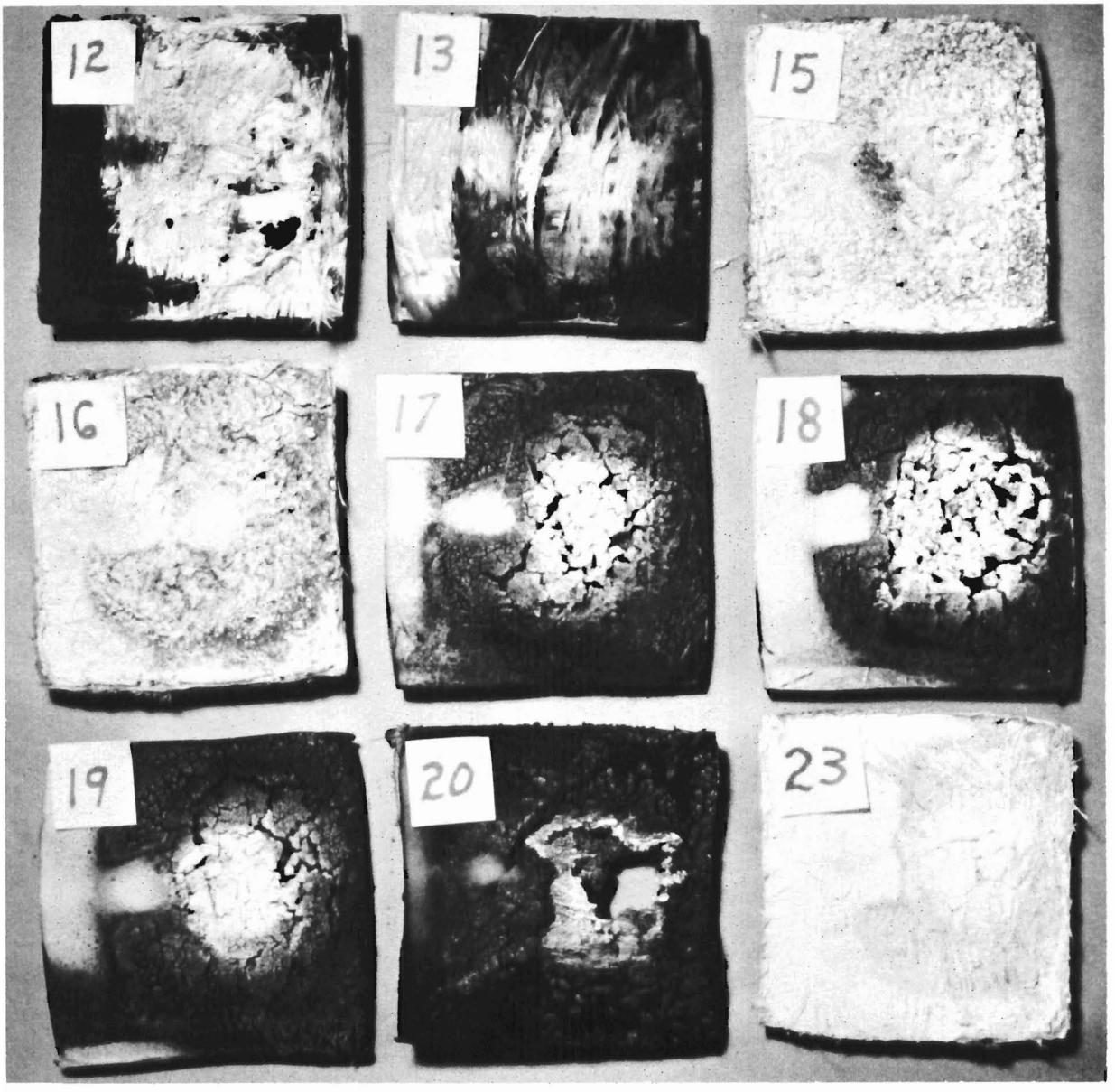


Figure 27 Flame Erosion Screening Test Specimens After Exposure (Tested to Failure)

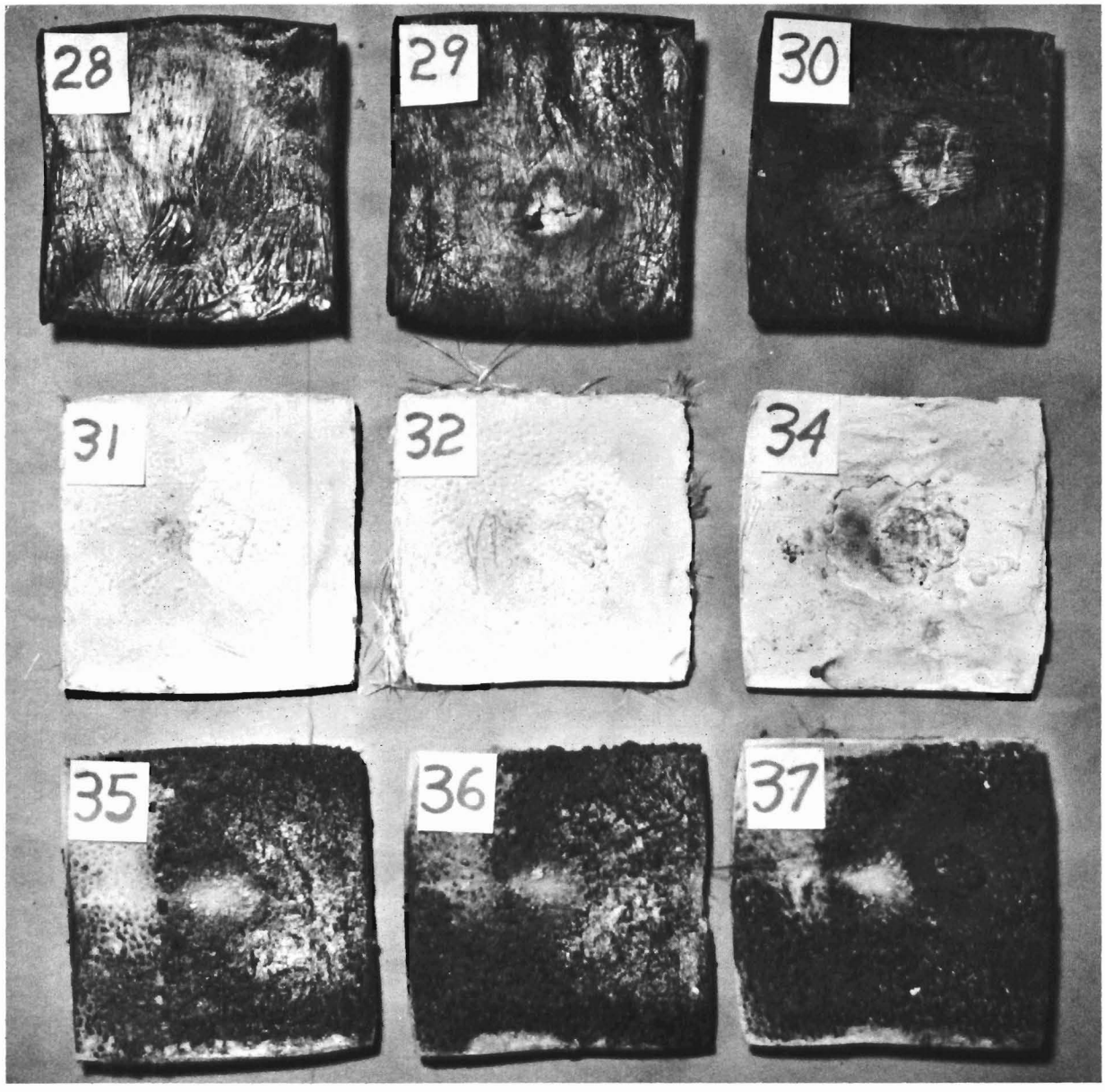


Figure 28 Flame Erosion Screening Test Specimens After Exposure (Tested to Failure)

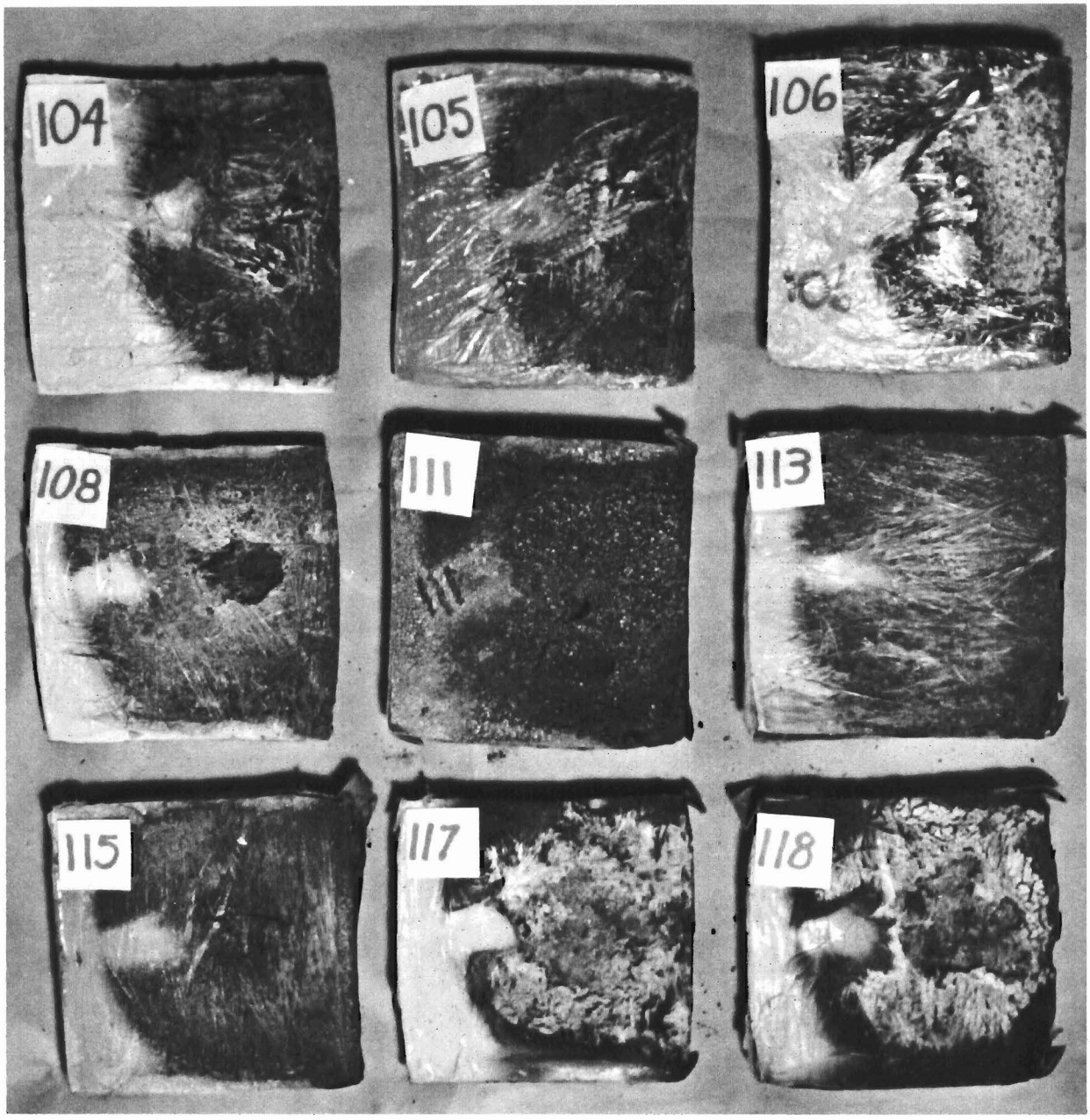


Figure 29 Flame Erosion Screening Test Specimens After Exposure (Tested to Failure)

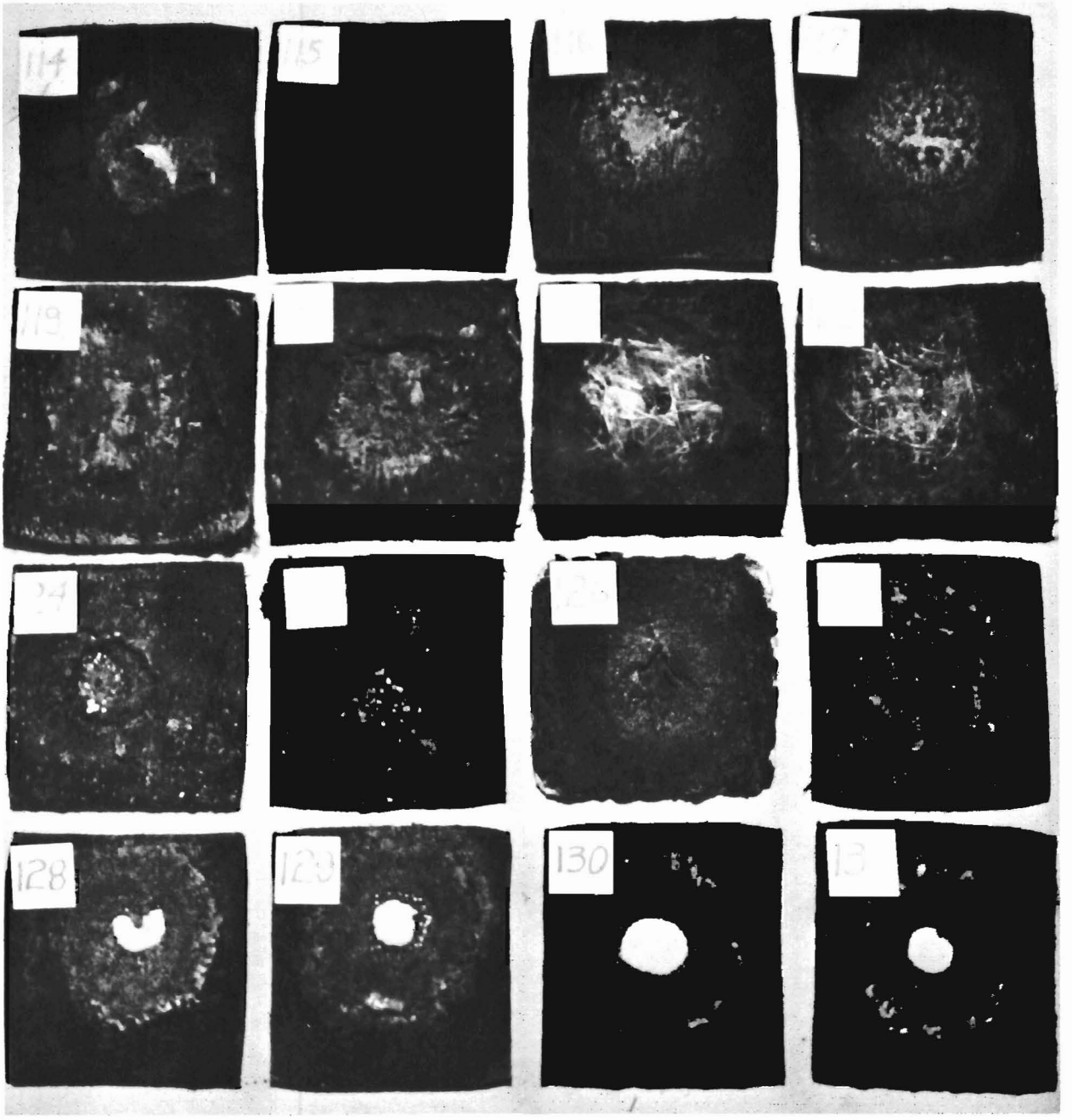


Figure 30 Flame Erosion Screening Test Specimens After Exposure (Tested to Failure)

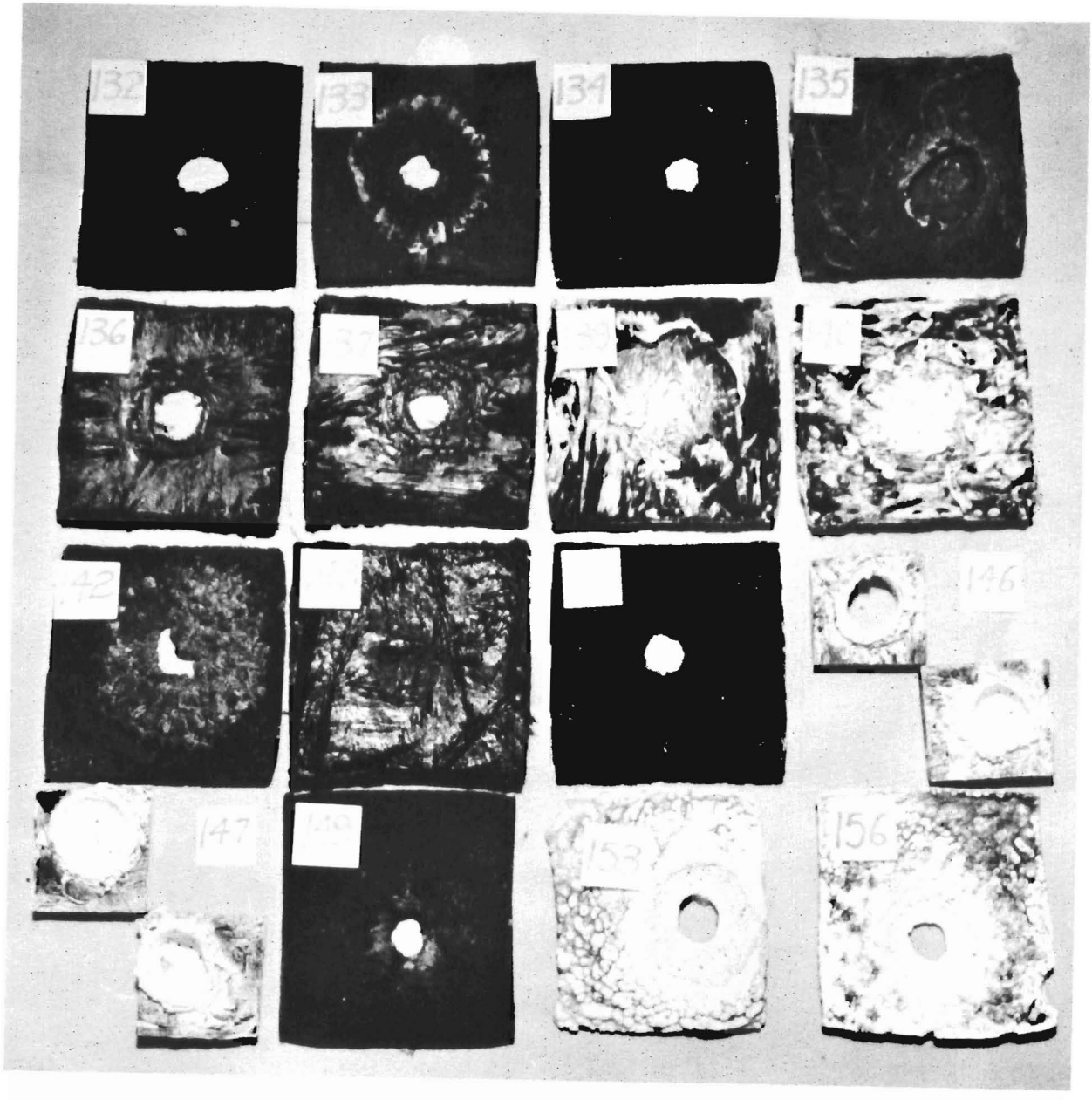


Figure 31 Flame Erosion Screening Test Specimens After Exposure (Tested to Failure)

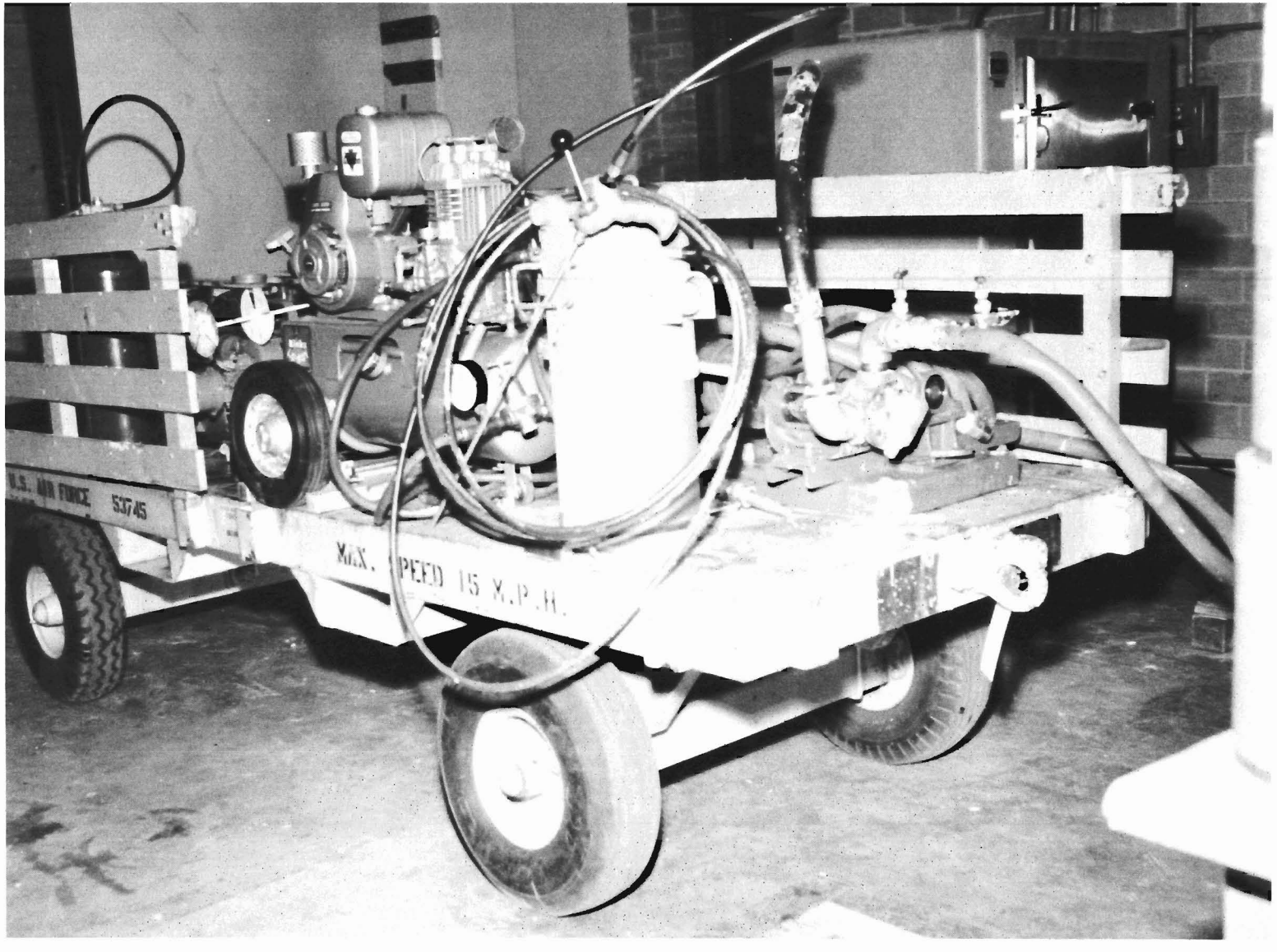


Figure 32 Experimental Application Equipment

Figure 33 Fiberglass Dispensing System

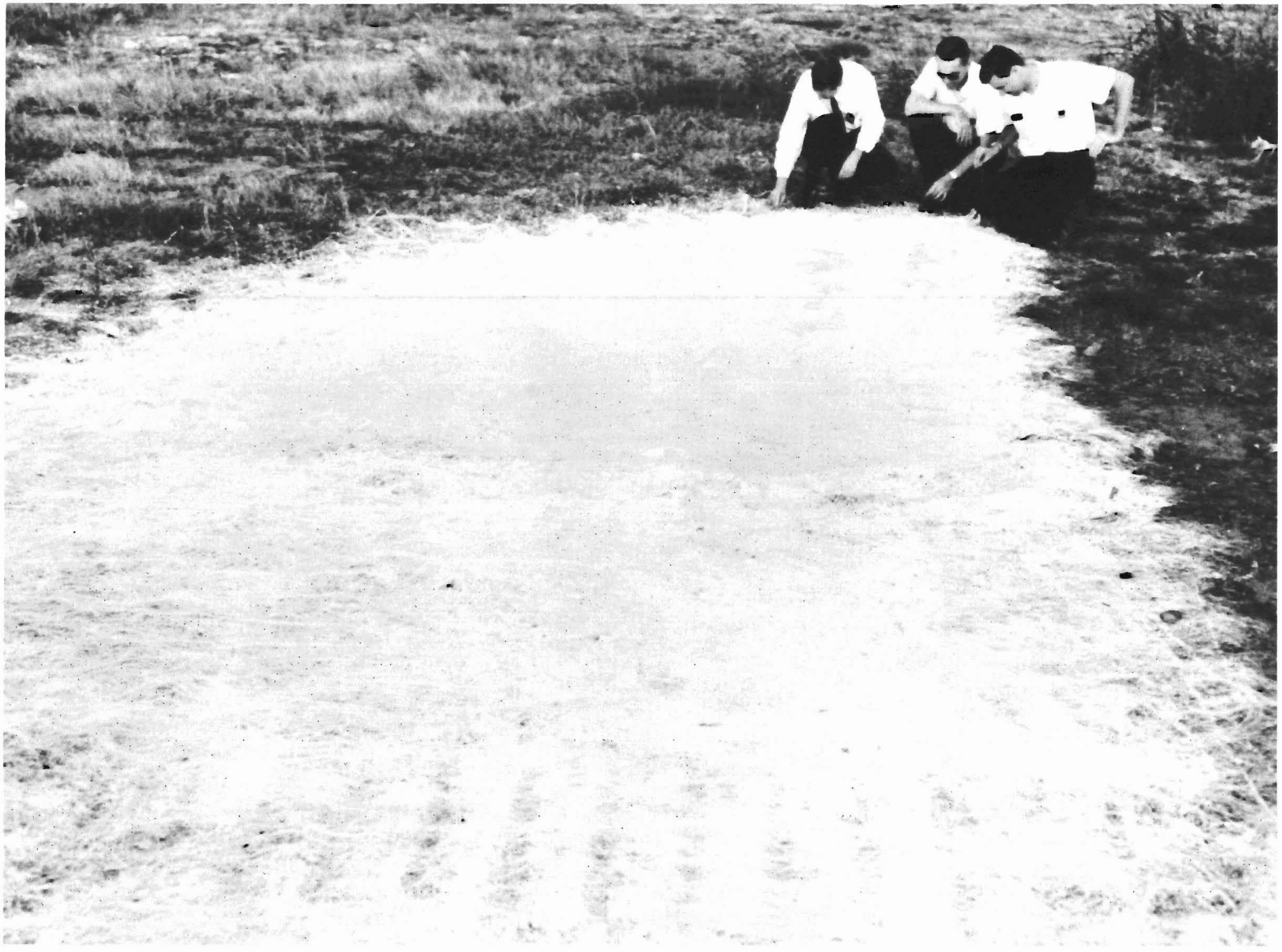


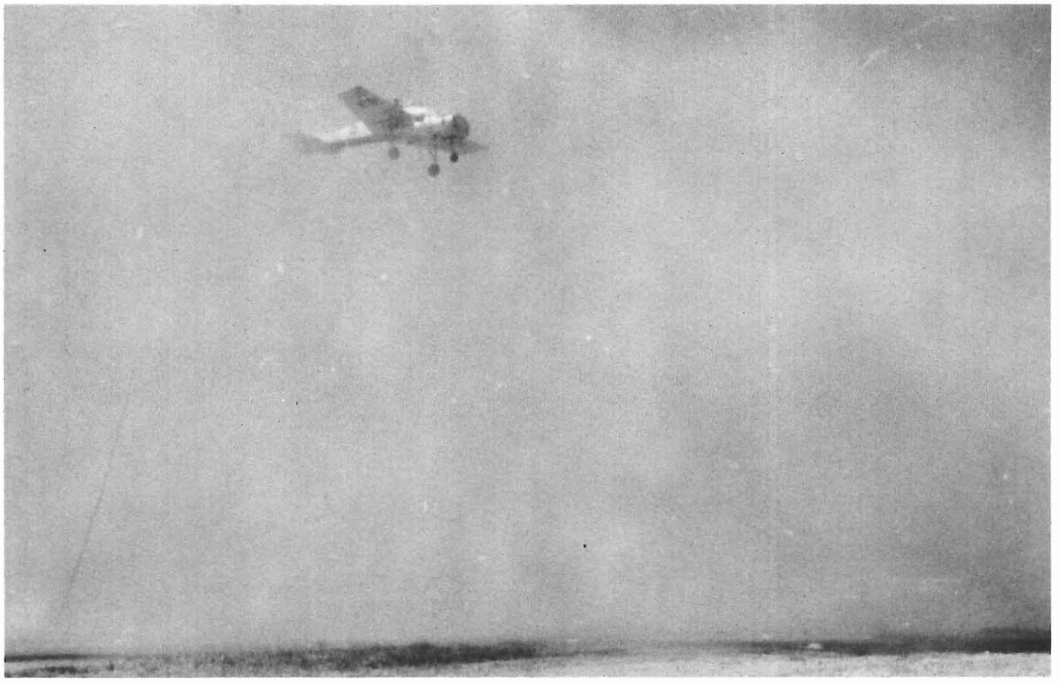
Figure 34 Equipment Checkout Trials Site

Figure 35 Field Demonstration Site Farrication

Figure 36 X-14A Aircraft Hovering Over Demonstration Site

Figure 37 X-14A Aircraft on Test Site

Figure 38 Demonstration Site After Initial Landings and Takeoffs



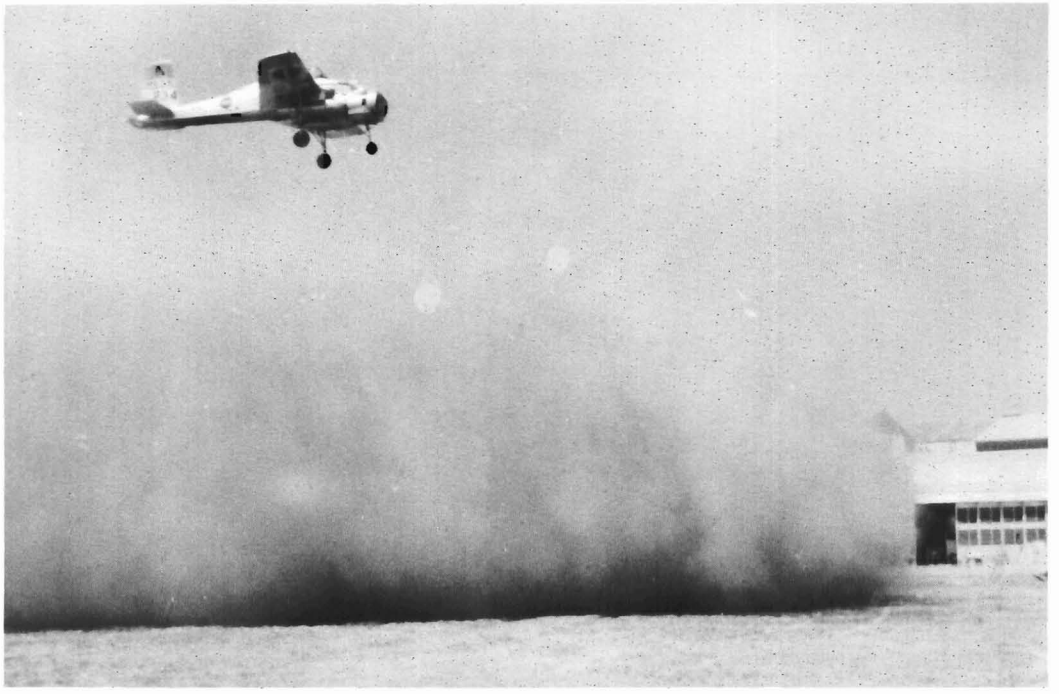


Figure 39 Surface Erosion and Dust Cloud Generated by X-14A Hovering Over Unprepared Area Adjacent to Demonstration Site

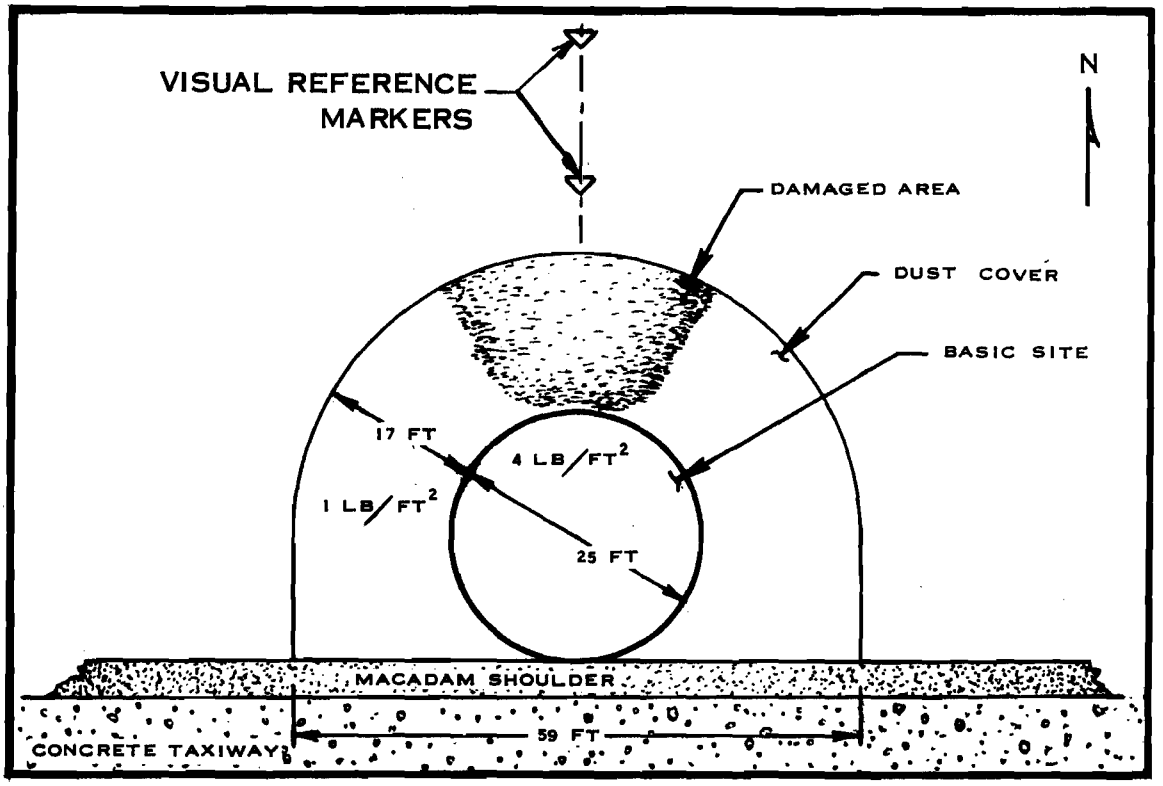


Figure 40 Field Demonstration Site, Moffett Field, California.

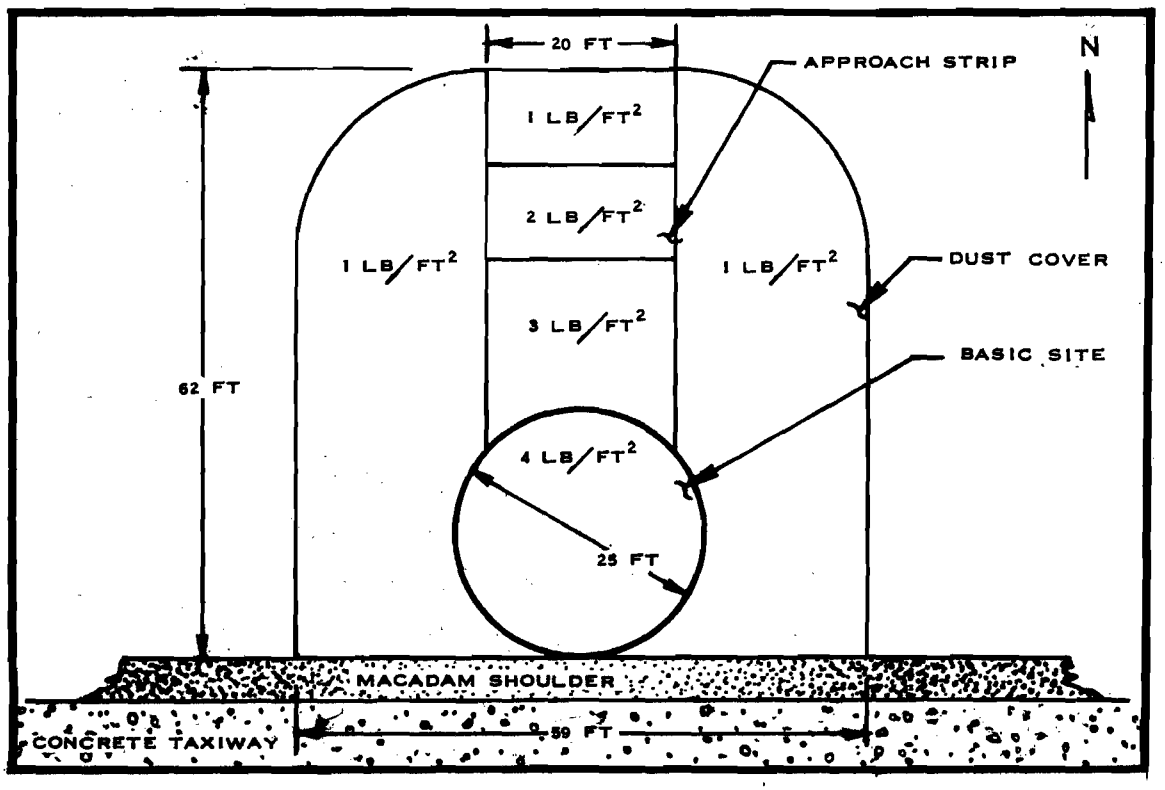


Figure 41 Modified Field Demonstration Site, Moffett Field, California

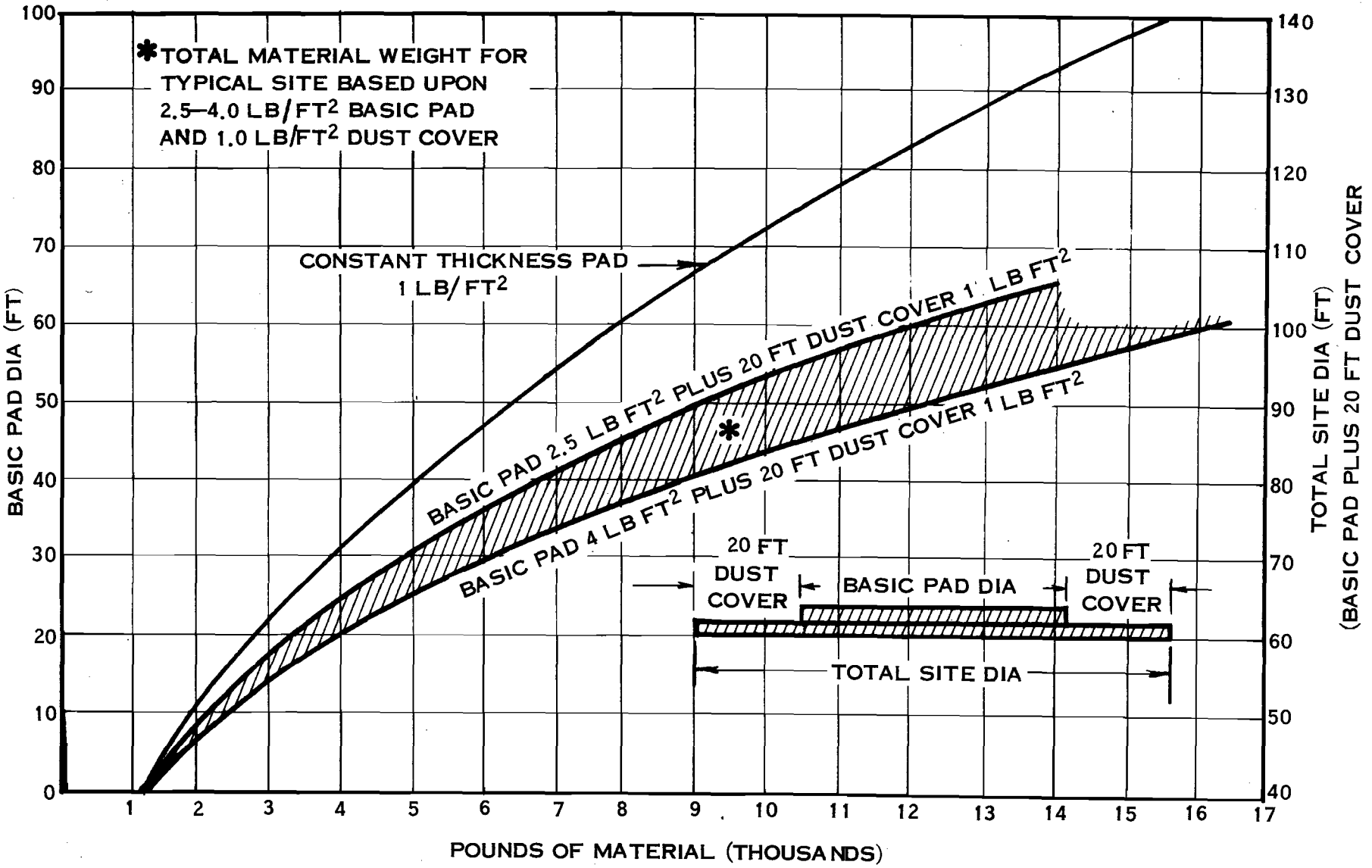


Figure 42 Total Material Weight vs Site Diameter

Table 1

Materials General Properties Chart

TYPE MATERIAL	REINFORCEMENT	PRODUCT NO.	VISCOSITY @ 75°F BASE RESIN, POISE	GEL TIME @ 75°F - MINUTES	CURE TIME @ 75°F - HOURS	HARDNESS ROCKWELL D 785	SPECIFIC GRAVITY	TENSILE STRENGTH P.S.I.	ELONGATION %	MOD. OF ELASTICITY TENSION X 10⁵ P.S.I.	FLEXURAL STRENGTH P.S.I.	IMPACT RESISTANCE IZOD FT LBS/IN. OF NOTCH 1/2 x 1/2 IN. NOTCHED BAR ASTM D-256	WATER ABSORPTION 24 HRS, 1/8" THICK ASTM D-570, %	WEATHER RESISTANCE	DEFLECTION UNDER LOAD ASTM D643°F	HEAT RESISTANCE CONTINUOUS, °F	FLAMMABILITY ASTM D-635	REMARKS
Casein	None	Typical	*	*	*	M70 M100	 1.35	 10,000	 2.5	5.1 5.7	10,000 18.000	 1.0	 -	 Fades	 300	 275	Very Low	
Diallyl Phthalate	None	Typical	*	*	*													Cast
Diallyl Phthalate	Mineral Filler	Typical	*	*	*	M100 M103	1.65 1.90	4,000 8,000	 -	12 22	6,000 9,000	0.3 0.45	0.2 0.5	Excel.	300 420	350 450	Self Extin	
Diallyl Phthalate	Glass Filler	Typical	*	*	*	M108 M110	1.55 1.90	5,000 9,000	 -	15 22	9,500 18,000	0.5 15	0.12 0.35	 Excel.	325 500	350 450	Self Extin	
Phenoxy	None	Union Carbide Phenoxy																
Phenol Formaldehyde	None	Typical	*	*	*	M124 M128	1.25 1.30	7,000 8,000	1.0 1.5	7.5 10	10,000 30,000	0.20 0.36	0.1 0.2	Good Darkens	240 260	250	Very Low	Molded Properties
Phenol Formaldehyde	Asbestos	Typical	*	*	*	M95 M115	1.45 1.90	5,500 7,500	0.18 0.50	 30	8,000 14,000	0.27 3.5	0.1 0.5	Good Darkens	300 400	350 500	 None	Molded Properties
Phenol Formaldehyde	Glass Fiber	Typical	*	*	*	M95 M100	1.75 1.95	5,000 10,000	 0.2	 33	10,000 60,000	10 50	0.1 1.2	Good Darkens	 600+	350 500	 None	Molded Properties
Silicone Resins	Glass Fiber	Typical	-	-	-	 M84	1.68 2.00	4,000 5,000	 -	 -	10,000 14,000	3 15	0.1 0.2	None Slight	 900+	 600+	None Slow	
Phenolic	None	Typical				M93 M120	1.30 1.32	6,000 9,000	1.5 2.0	 4.5	11,000 17,000	0.25 0.40	0.3 0.4	 Fades	165 175	160	Very Slow	Cast
Phenolic	Mineral Filler	Typical				M85 Mk20	1.68 1.70	4,000 9,000	- 	- 	9,000 12,000	0.35 0.50	0.12 0.36	 Darkens	150 175	 160	Good	Cast
Phenolic	Asbestos Filler	Typical				R110	1.70	3,000 6,000	-	 18.8	5,000 8,000	-	-	Slight Darkening	-	 300	Good	Cast
Urethane Foams	None	Typical					0.02 1.12	12- 8,000	150- 500			0.05- 1.0	0.2- 4.0					
Epoxy Bis-Phenol-A	None	Typical	0.9	2	4	M80 M110	1.1 1.4	4,000 13,000	3 6	3 6	13,000 21,000	0.2 1.0	0.08 0.15	Good	115 550	250 600	Slow	
Epoxy Bis-Phenol-A	None	Typical	0.9	2	4	M80 M110	1.1 1.4	4,000 13,000	3 6	3 6	13,000 21,000	.2 1.0	0.08 0.15	 Good	115 550	250 550	 Slow	Cast
Epoxy Bis-Phenol-A	Silica Powder	Typical		45	4	M85 M120	1.6 2.0	7,000 13,000	1 3		8,000 14,000	0.30 0.45	0.04 0.10	 Good	160 550	250 550	Self Extin	Cast

Table 1

Materials General Properties Chart (Continued)

TYPE MATERIAL	REINFORCE-MENT	PRODUCT NO.	VISCOSITY @ 75° F	BASE RESIN, POISE	GEL TIME @ 75° F - MINUTES	CURE TIME @ 75° F - HOURS	HARDNESS ROCKWELL D 785	SPECIFIC GRAVITY	TENSILE STRENGTH P.S.I.	ELONGATION %	MOD. OF ELASTICITY TENSION X 10⁵ P.S.I.	FLEXURAL STRENGTH P.S.I	IMPACE RESISTANCE IZOD FT. LBS/IN. OF NOTCH 1/2 X 1/2 IN. NOTCHED BAR ASTM D-256	WATER ABSORPTION - 24 HRS, 1/8" THICK ASTM D-570, %	WEATHER RESISTANCE	DEFLECTION UNDER LOAD-ASTM D643°F	HEAT RESISTANCE CONTINUOUS, °F	FLAMMABILITY ASTM D-635	REMARKS
Polyvinyl Dichloride	None	Typical	*	*	*	117	1.50	7,500 9,000	4.5	4.0 4.5	14,500 17,000	0.8 5.0	0.15	-	215 220	210	Self Extin	
Polyvinyl Fluoride	None	DuPont Tedlar	*	*	*	P80	1.76 1.77	7,000	100 300	1.2	-	3.5	0.4	Slight Bleaching	300	300	Self Extin	Shore hardness
Urethane Elastomers	None	Goodrich Estane 120	*	*	*	70 96	1.20	5,800	580	-	-	-	-	Slight Yelowing	-	180	Slow	Shore hardness
Acetals	None	Typical DuPont Delrin	*	*	*	M-76 R-118	1.42	8,800 10,000	15 40	3.7 4.1	12,000 14,000	1.1 4.0	0.12 0.25	Good	255/64 psi	185 250	Slow	*Not applicable to prefabricated thermoplastics
Acrylic	None	Typical	*	*	*	M-80 M-100	1.17 1.20	8,000 11,000	2 7	3.5 5.0	12,000 17,000	0.4 0.5	0.3 0.4	Good	150 210	140 200	Slow	
Ethyl Cellulose	None	Typical	*	*	*	R-50 R-115	1.09 1.17	2,000 8,000	5 40	1.0 3.0	4,000 12,000	2.0 8.5	0.8 1.8	Fair	115 190	115 185	Slow	
Cellulose Acetate	None	Typical	*	*	*	R-95 R-120	1.28 1.32	4,500 8,000	20 50	3.0 4.0	6,000 10,000	1.0 3.0	2.0 4.5	Fair	130 160	140 220	Slow	
Cellulose Ace. Butyrate	None	Typical	*	*	*	R-30 R-115	1.15 1.22	2,600 6,900	60 100	2.0 2.5	4,000 9,000	0.8 6.3	0.9 2.2	Fair	115 200	140 220	Slow	
Polyamide (Nylon)	None	Typical	*	*	*	R-111 R-118	1.09 1.14	7,000 12,000	25 200	2.6 4.0	8,000 13,800	1.0	0.4 1.5	Good Discolors	300 360	270 300	Self Extin	
High Density Polyethylene	None	Typical	*	*	*	D-60 D-70	.94 .96	3,100 5,500	15 100	.6 1.5	1,000	1.5 20.0	0.01	Poor	140 180	250	Very Slow	
Poly-Propylene	None	Typical	*	*	*	R-85 R-110	.90 .91	4,800 6,000	200 700	1.6 2.0	6,000 8,000	0.63 6.0	0.01	Poor	210 240	250 320	Slow	
Chlorotri-fluoro-ethylene	None	Typical	*	*	*	R-110 R-115	2.10 2.20	4,500 6,000	30 250	1.5 3.0	7,400 9,300	0.8 5.0	0.00	Excel.	258	350 390	None	
Tetrafluoro-ethylene	None	Typical	*	*	*	R-25	2.14 2.17	2,700 3,100	250 380	.5	-	No Break	0.01	Excel.	-	400	None	
Styrene	None	Typical	*	*	*	M-65 M-80	1.04 1.06	5,000 9,000	1.0 2.5	4 5	8,700 14,000	0.254 0.40	0.03 0.05	Yellows	150 195	150 170	Slow	

*Not applicable to prefabricated materials.

Table 1

Materials General Properties Chart (Continued)

TYPE MATERIAL	REINFORCEMENT	PRODUCT NO.	VISCOSITY @ 75°F	BASE RESIN, POISE	GEL TIME @ 75°F MINUTES	GEL TIME @ 75°F HOURS	CURE TIME @ 75°F	HARDNESS ROCKWELL D 785	SPECIFIC GRAVITY	TENSILE STRENGTH P.S.I.	ELONGATION %	MOD. OF ELASTICITY TENSION X 10^5 P.S.I.	FLEXURAL STRENGTH P.S.I.	IMPACT RESISTANCE IZOD FT LBS/IN. OF NOTCH 1/2 x 1/2 IN. NOTCHED BAR ASTM D-256	WATER ABSORPTION 24 HRS, 1/8" THICK ASTM D-570, %	WEATHER RESISTANCE	DEFLECTION UNDER LOAD -ASTM D643°F	HEAT RESISTANCE CONTINUOUS, °F	FLAMMABILITY ASTM D-635	REMARKS
Poly-carbonate	None	Typical	*	*	*	M-70 R-118	1.20	8,000 9,500	60 100	3.2	11,000 13,000	12.0 16.0	0.15	Slt Clr & Embr.	270 280	250	Self Extin		264 psi
Vinyl Butyral	None	Typical	*	*	*	10 100	1.05	500 3,000	150 450	-	Varies with plasticizer		1.0 2.0	Slight	-	-	Slow		Shore hardness
Chlorinated Polyether	None	Typical	*	*	*	R-100	1.40	6,000	60 160	1.6	5,000	0.4	0.01	Slight loss in duct	285	290	Self Extin		
Vinyl Chloride	None	Typical	*	*	*	70 90	1.35 1.45	5,000 9,000	2 40	3.5 6	10,000 16,000	0.4 20.0	0.07 0.4	-	130 165	120 160	Self Extin		Shore hardness
Vinyl Formal	None	Typical	*	*	*	M85	1.20 1.40	10,000 12,000	5 20	3.5 6	17,000 18,000	0.8 1.4	0.5 3.0	Slight	150 170	120 150	Slow		
Furane	Asbestos Filler	Typical	10 Solid	10 1440	*	R110	1.75	3,000 4,500	-	15.8	6,000 9,000	-	0.01 0.20	Excel	-	265 330	Slow		
Melamine Formaldehyde	None	Typical	*	*	*	-	1.48	-	-	-	11,000 14,000	-	0.3 0.5	Fades	298	210	Self Extin		
Melamine Formaldehyde	Asbestos Filler	Typical	*	*	*	M110	1.7 2.0	5,500 7,000	0.3 0.4	19.5	9,000 11,000	0.28 0.4	0.08 0.14	Color Change	265	250 400	Self Extin		
Melamine Formaldehyde	Glass Fiber	Typical	*	*	*	-	1.8 2.0	5,000 10,000	-	24	15,000 23,000	4 6	0.09 0.21	Color Change	400	500 400	Self Extin		
Silicates & Oxides		Sauereisen Cement Powder 29F & B		90 120					400		0.0045						None Burning		
Polyesters	None	Typical		5	1	M-70 M-115	1.0 1.5	800 10,000	5 310	3 6.4	8,500 18,300	0.2 7.0	125 135	Yellows Slightly	140 400	250	Flammable and self exting		Rigid & flexible grades
Polyesters	None	American Cynamid Laminac 4128	65 85	15 90	.5 1.5				9,000	1.8	6.		2.6		Good				
Polyesters	None	Hooker Chemical Hetron 32-A	23	5 6.5			1.31		9,300	4.3			0.237	0.102		170			

*Not applicable to prefabricated materials.

Table 1

Materials General Properties Chart (Continued)

TYPE MATERIAL	REINFORCEMENT	PRODUCT NO.	VISCOSITY @ 75° F BASE RESIN, POISE	GEL TIME @ 75° F MINUTES	CURE TIME @ 75° F HOURS	HARDNESS ROCKWELL D 785	SPECIFIC GRAVITY	TENSILE STRENGTH P.S.I.	ELONGATION %	MOD. OF ELASTICITY TENSION X 10^5 P.S.I.	FLEXURAL STRENGTH P.S.I	IMPACT RESISTANCE IZOD FT. LBS/IN. OF NOTCH 1/2 X 1/2 IN. NOTCHED BAR ASTM D-256	WATER ABSORPTION 24 HRS, 1/8" THICK ASTM D-570, %	WEATHER RESISTANCE	DEFLECTION UNDER LOAD- ASTM D643°F	HEAT RESISTANCE CONTINUOUS, °F	FLAMMABILITY ASTM D-635	REMARKS
Epoxy Bis-Phenol-A	None	Shell-EPON 828 Cat U (100 Poise)	100 160	45	4			10,500		5.1								
Epoxy Bis-Phenol-A	None	EPON 828 Cat DIA (10 Poise)	100 160	15 30	4			10,000 10,000		4.4 4.4	4.4							
Epoxy Bis-Phenol-A	None	EPON 820 Cat U	40 100	45	4			10,000										Similar to 815 Resin
Epoxy Bis-Phenol-A	None	EPON 815 Cat TETA	5 9									0.5			175			
Epoxy Bis-Phenol-A	None	DOW DER 331 Cat TETA	110 140	15	4	M160	1.16	9,000	5.2	3.9	12,900	0.4			271			
Epoxy Bis-Phenol-A	None	Thermoset Epoxy 08 Cat 38		2														Thermoset Plastics Inc, 4015 Millerville Rd., Indianapolis 5, Indiana
Epoxy Bis-Phenol-A	None	Richardson Pyro Stop E-100, Cat Resin A+ TETA	60 80				1.42											The Richardson Co, 2700 Lake Street Melrose Park, Illonois
Epoxy Polysulfide	None	Typical	10 Solid			M80 M110	1.11 1.40	4,000 13,000	3 6	3.5	13,300 21,000	.2 1.0	0.08 0.15	Excell	115 550	250 550	Slow	
Epoxy Bis-Phenol-A	Glass Fiber	Typical	10 Solid	10 240	*	M100 M108	1.8 2.0	14,000 30,000	4	3.4	20,000 60,000	8 25	0.05 0.095	Slight	400 500	330 500	Self Extin	Molded
Epoxy Bis-Phenol-A	Mineral Filler	Typical	10 Solid	10 240	*	M101	1.6 2.06	5,000 7,000	- -	- -	10,000 15,000	0.25 0.40	0.1	Slight	250 450	300 500	Self Extin	Molded
Ceramic		Rusco 8 X 750						4,000 - 5,000										
Ceramic		Sauereisen 29						4,000 - 5,000										
Ceramic Gel		Siroc						No Structural Data										

Table 2
Summary of Flame-Erosion Screening Test Data

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
ABS	43	Royalite 6511 - Pre-fab.	----	Pre.fab.	---	---	----	.125	84.5	0.80	-----	Cont.	Heavy	2(1)	---	Red	Immed. warp & buckle
Asbestos Phenolic	158	260 QMC Phenolic 10 Cat.; 15 Glass	1.50	.13	---	75	20	.500	285	2.50	3	5	Light	2(3)	Poor	Dark	(3) distance - 4"
	61	Pre-fab	---	---	---	---	---	.250	115	2.25	---	---	---	10(2)	---	Brown	
Ceramic	1A	210 Siroc #1; 22.5 Siroc#2 22.5 H_2O; 20 Chopped Glass	1.54	.10	1.37	80	60	1.00	---	2.50	12	None	None	10(1)	Excellent	Fiberglass	Very fluid mix
Ceramic	2A	120 Siroc #1; 20 Siroc #2; 20 Siroc #3; 40 H_2O; 10 Fiberglass	1.54	.10	1.37	80	---	1.00	---	2.13	5	None	None	10(1) 3(2)	Excellent	Blue	Requires vigorous mix.
Ceramic	3A	220 Glassrock S-205; 44 H_2O; 15 Chopped glass.	Powder	.01	1.90	80	60	.250	---	2.50	---	---	---	---	---	Smooth White	Thick; will not pour. N. A. **
Ceramic	4A	140 Siroc #1; 10 Siroc #2; 30 Siroc #3; 20 H_2O	1.54	.10	1.37	80	50-60	---	---	1.40	---	---	---	---	Poor	Blue	Jelled during mix.
Ceramic	5A	140 Siroc #1; 20 Siroc #2; 10 Siroc #3; 30 H_2O; 10 Glass roving	1.54	.10	1.37	80	50-60	1.00	---	1.75	4	None	None	10(1)	Good	Blue	Absorbed by sponge
Ceramic	6A	120 Siroc #1; 20 Siroc #2; 30 Siroc #3; 30 H_2O; 10 Glass roving	1.54	.10	1.37	80	50-60	---	---	---	---	---	---	---	---	Blue	Jelled during mixing
Ceramic	7	210 Siroc #1; 22.5 Siroc #2; 22.5 H_2O; 12 Glass mat; 10.5 Cement	1.54	.13	---	80	---	.375	---	2.50	12	None	None	10(1) 10(2)	---	White	Jelled in 2 hours
Ceramic	8	210 Siroc #1; 22.5 Siroc #2; 22.5 H_2O; 5 Cement; 12.5 Glass	1.54	.13	---	80	---	.375	---	2.50	12	---	---	10(2)	---	White	Jelled during add. of Siroc #2
Ceramic	14	225 Siroc #1; 45 Siroc #2; 15 Fiberglass	1.54	---	---	78	30	---	285	2.50	---	---	---	---	Poor	---	Jelled during add. of Siroc #2.
Ceramic	15	220 Siroc #1; 22.5 Siroc #2; 22.5 Siroc #3; 15 Glass	1.54	.13	1.90	80	30	1.00	280	2.50	24	---	---	10(2)	Fair	Blue lumpy	Jelled during mix, poured
Ceramic	16	200 Siroc #1; 20 Siroc #2; 40 Siroc #3; 15 Glass.	1.54	.13	1.90	80	30	---	275	2.50	24	---	---	10(2)	Fair	Blue lumpy	Jelled during mix
Ceramic	21	120 Siroc #1; 50 Siroc #2; 20 Siroc #3; 70 H_2O; 15 Asbestos	1.54	.10	1.37	80	30	---	275	2.50	---	---	---	---	Poor	Blue lumpy	Jelled while pouring
Ceramic	22	130 Siroc #1; 50 Siroc #2; 10 Siroc #3; 70 H_2O; 15 Fiberglass	1.54	.13	---	80	30	---	275	2.50	---	---	---	---	Good	Blue lumpy	Jelled while pouring; did not harden in 24 hrs.

*(1) Gas torch (2) = Plasma ARC (3) = Oxy-acetylene torch **N. A. = not adaptable to program.

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Ceramic	23	160 Siroc #1; 30 Siroc #2; 30 Siroc #3; 60 H_2O; 15 Fiberglass	1.54	.13	1.90	80	30	---	295	2.50	24	---	---	10(2)	Good	Blue lumpy	Considerable ppt.
Ceramic	31	180 Rusco BX-750; 90 Binder; 15 Glass	Powder	.21	2.17	75	45	.25	285	2.50	12	None	None	10(1) 10(2)	Good	White	Did not wet all of glass
Ceramic	32	195 Rusco BX-750; 65 Binder; 15 Glass	Powder	.21	2.17	75	45	.25	275	2.50	12	None	None	10(1) 10(2)	Fair	White	Did not wet all of glass
Ceramic	33	195 Sauereisen #29; 65 Binder; 15 Glass	Powder	.23	2.17	72	22	.25	275	2.50	4	None	None	10(1) 10(2)	Fair	White	Large surface blisters on first run.
Ceramic	34	180 Sauereisen #29; 90 Binder; 15 Glass	Powder	.23	2.17	72	22	.25	285	2.50	4	None	None	10(1) 9(2)	Good	White	One large surface blister
Ceramic	62	210 Siroc #1; 22.5 Siroc #2; 22.5 H_2O; 15 Filler; 10 Glass	1.00	.10	1.40	75	20	1.00	280	2.50	5.75	---	---	3(2)	Poor	Rough, dark	Jelled but stirring broke u
Ceramic	86	220 Siroc #1; 22.5 Siroc #2; 22.5 H_2O; 10 Glass mat	1.54	.13	1.25	60	44	.125	280	2.50	16	None	Steam	6(1)	Good	Blue	Did not set in 16 hrs; cracked
Ceramic	94	220 Siroc #1; 22.5 Siroc #2; 22.5 H_2O; 10 Glass	1.54	.13	1.20	60	43	.125	275	2.5	30	---	---	6(2)	Good	Blue	Mat'l. not rigid in 24 hrs.
Ceramic	100	220 Siroc #1; 45 Siroc #2; 60 H_2O; 15 Fiberglass	1.54	.13	---	75	43	.375	280	2.5	24	---	---	10(2)	Good	Blue	----------
Ceramic	101	140 Siroc #1; 60 Siroc #2; 10 Asbestos; 60 H_2O; 15 Fiberglass	Paste	.13	---	75	30	.375	285	2.5	24	---	---	---	Poor	White	Asbestos made mixture pasty.
Ceramic	139	370 Sauereisen #29; 185 #29 Binder; 15 Glass	Powder	.23	---	75	20	.500	579	5.0	4	None	None	10(3)	Fair	White	(3) distance - 7"
Ceramic	140	same as above	Powder	.23	---	75	20	.500	579	5.0	4	None	None	10(3)	Fair	White	(3) distance - 7"
Ceramic	141	same as above	Powder	.23	---	75	20	.500	570	5.0	4	None	None	9(3)	Fair	White	(3) distance - 4"
Ceramic	146	same as above	Powder	.15	---	75	30	.500	570	5.0	24	---	---	9(3)	Fair	White	(3) distance - 4"
Ceramic	147	same as above	Powder	.15	---	74	24	.500	570	5.0	6.25	---	---	9(3)	Fair	White	(3) distance - 4"
Ceramic	148	same as above	Powder	.15	---	74	24	.500	570	5.0	6.25	---	----	10(3)	Fair	White	(3) distance - 4"
Ceramic	153	220 Siroc #1; 25 Siroc #2; 25 H_2O	1.54	.13	---	77	17	.500	270	2.5	16	None	None	4(3)	Good	Blue	(3) distance - 4"
Ceramic	154	220 Siroc #1; 25 Siroc #2; 25 Tap H_2O	1.54	.13	---	77	17	.500	270	2.5	16	None	None	4(3)	Good	Blue	(3) distance - 4"
Ceramic	155	200 Siroc #1; 20 Kaolin: 25 Siroc #2; 25 Tap H_2O	1.54	.13	---	77	17	.500	270	2.5	16	None	None	6(3)	Good	Light blue	(3) distance - 4"

*(1) Gas torch (2) Plasma ARC (3) Oxy-acetylene torch **N. A. = not adaptable to program

Table 2
Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Ceramic	156	180 Siroc #1; 40 Zr. pwd; 25 Siroc #2; 24 tap H_2O.	1.54	.13	---	77	17	.375	270	2.5	16	None	None	4(3)	Good	Light blue	(3) distance - 4"
Ceramic	157	190 Siroc #1; 25 Siroc #2; 30 Kaolin; 25 H_2O	1.54	.20	---	74	21	.375	270	2.5	5.5	None	None	3(3)	Good	-----	(3) distance - 7"
Ceramic	168	168 Siroc #1; 25 Siroc #2; 20 Siroc #3; 65 H_2O; 15 Glass	1.50	.13	---	75	35	1.125	285	2.5	336	None	None	3(3)	Good	Blue	(3) distance - 7"
Ceramic	169	same as above	1.50	.13	---	75	35	.375	285	2.5	336	None	None	10(3)	Good	Blue	(3) distance - 7"
Ceramic	170	140 Siroc #1; 35 Siroc #2; 30 Siroc #3; 65 H_2O; 15 Glass	1.50	.13	---	75	35	1.125	285	2.5	336	None	None	3(3)	Fair	Blue	(3) distance - 7"
Ceramic	171	160 Siroc #1; 30 Siroc #2; 30 Siroc #3; 65 H_2O; 15 Glass	1.50	.13	---	75	35	1.125	290	2.5	336	None	None	6(3)	Fair	Blue	(3) distance - 7"
Ceramic	172	160 Siroc #1; 30 Siroc #2; 30 Siroc #3; 60 H_2O; 15 Glass	1.50	.13	---	75	30	1.125	295	2.5	336	None	None	3(3)	Poor	Blue	(3) distance - 7"
Epoxy	7A	150 Epon 828; 22.5 Phenolic Microballons; 30 curing Agent U; 10 Fiberglass	1.56	.10	1.17	85	50-60	.375	---	1.9	2	5	Heavy	10(1) 1(2)	Fair	Dark Brown	Thick mix; hard to pour; weak crust
Epoxy	8A	220 Dow 332; 20 DTA; 30 Polystyrene beads; 14 Glass	---	---	---	80	---	2.000	---	2.5	6	20	Heavy	1(1)	Poor	White	N. A. **
Epoxy	9A	200 Dow 332; 50 Boric acid; 20 DTA	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Jelled during mix; N. A. **
Epoxy	10A	182 Epon 828; 18 DTA; 64 Silica flour; 20 Glass roving	1.56	.10	1.17	80	---	---	---	2.5	12	---	---	3(2) 3(2)	---	White	Mat'l. is thixtropic
Epoxy	11A	175 Epon 828; 17.5 Boric acid; 35 Curing agent D; 10 Chopped glass	3.00	.10	1.17	85	---	.625	---	2.1	2	5	Moderate	10(1) 2(2)	Good	Glossy White	Thick but easy to pour
Epoxy	12A	245 Dow 332; 24.5 DTA; 14 Chopped glass foving	5.0	.10	1.2	80	50-60	1.00	---	2.5	4	5	Moderate	10(1) 1(2)	Excellent	Clear Amber	
Epoxy	13A	140 Epoxylite CF-8705; 28 Hardener; 10 Glass	---	Powder	---	80	---	.50	---	1.5	12	4	Light	10(1) 1(2)	Good	Green	Hardener not readily sol. in the resin.
Epoxy	12	130 Epon 828; 100 Al_2O_3; 15 DTA; 15 Glass; 15 PGE	2.0	.10	---	80	25	.75	275	2.5	12	---	---	7(2) 7(2)	Good	Smooth White	Very fluid mix; wetted sand
Epoxy	13	100 Epon 828; 150 Al_2O_3; 10 DTA; 15 Glass	4.0	.10	---	80	25	.75	285	2.5	24	---	---	1(1) 2(2)	Good	Smooth White	
Epoxy	54	40 Glidcrete Resin; 5 Cat.; 225 Glidcrete Grout; 15 Glass	Paste	.10	1.7	80	26	.40	---	2.5	24	Continuous	Heavy	10(1)	Poor		Very thick paste would not pour; caught fire on 3rd cycle.

*(1) Gas torch (2) Plasma arc (3) Oxy-acetylene torch **N. A. = not adaptable to program

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Epoxy	99	145 Epon 815; 85 Al_2O_3; 40 Curing agent U; 15 Fiberglass	1.10	30	1.25	75	43	1.0	285	2.5	24	---	---	--- 6(2)	Fair	Amber	
Epoxy	136	220 Epon 815; 50 Curing agent U; 15 Fiberglass	1.00	5-9	---	75	23	.50	285	2.5	4.5	15 up	Heavy	2(3)	Good	Clear	(3) distance - 7" Internal cracking
Epoxy	137	220 Epon 815; 50 Curing agent U; 15 Fiberglass	1.00	5-9	---	75	23	.50	285	2.5	4.0	15 up	Heavy	3(3)	Good	Clear	(3) distance - 7" Internal cracking
Epoxy	138	220 Epon 815; 50 Curing agent U; 15 Fiberglass	1.00	5-9	---	75	23	.50	285	2.5	4.0	15 up	Heavy	11(3)	Good	Clear	(3) distance - 7"
Epoxy	143	200 Epon 815; 50 Curing agent U; 30 H_3BO_3; 15 Glass	1.00	5-9	---	75	22	.60	295	2.5	4.0	10	Heavy	1(3)	Good	White	(3) distance - 4" Shut down for rig repair.
Epoxy	144	200 Epon 815; 40 Curing agent U; 30 H_3BO_3; 15 Glass	1.00	5-9	---	75	22	.60	285	2.5	4.0	15	Heavy	3(3)	Good	White	Burn thru after 5 sec. of 3rd cycle. (3) distance - 4"
Epoxy	145	200 Epon 815; 40 Curing agent U; 30 H_3BO_3; 15 Glass	1.00	5-9	---	75	22	.60	285	2.5	36	15	Heavy	2(3)	Good	White	(3) distance - 4"; gel in 1 hour
Epoxy-Novalak	76	160 DEN 438; 40 Curing agent U; 60 Al_2O_3; 10 MgO; 10 Glass mat	Syrup	---	1.3	73	11	.50	280	25	30	---	---	--- 1(2)	Poor	White	DEN 438 had to be warmed to 150°F to pour.
Epoxy-Novalak	77	160 DEN 438; 20 Curing agent U; 20 Curing agent Z; 60 Al_2O_3; 10 Glass mat	Syrup	---	1.3	75	11	.38	270	2.5	30	---	---	--- 1(2)	Very Poor	Brown	Set 15 min. Curing agent Z and DEN 438 must be warmed to pour.
Epoxy-Polyamide	14A	125 Epon 828; 50 Polyamide 125; 13 Curing agent U; 15 Fiberglass	1.56	1.00	1.17	80	---	.50	---	1.75	6	9	Moderate	10(1) 1(2)	Fair	Clear Amber	Viscous but could be poured
Pre-fab Foam	173	TD-101-67 from ASD	Unknown	Unknown	---	---	---	1.8	---	2.5	---	0	Light	5(3)			(3) distance - 3.5 to 5".
Furan	15A	200 Jet-Kote X-8; 50 Catalyst TS; 7 Glass	---	---	---	90	50-60	1.0	---	2.25	36	5	Moderate	10(1) 10(2)	Good	Smooth black	Penetrated sand; shows promise
Furan	11	170 Jet Kote X-8; 50 Eccospheres R; 34 Catalyst TS	650	---	2.5	80	35	---	274	2.5	---	---	---	---	Fair	Smooth black	Did not set in 24 hours
Furan	24	230 14383 Furfuryl; 11.5 Asbestos; 26 17932 Accel.; 4 PTSA mix	57.5	Powder	---	80	30	.5	272	2.5	1.5	30	Heavy	10(1)	Poor	Bubbles on surface	Barely pourable; large cracks
Furan	25	230 16470; 16.5 Asbestos; 16 17932; 8 PTSA mix	100	Powder	---	80	28	.50	286	2.5	72	20	Heavy	10(1)	Good	Brown	Did not cure in 16 hours
Furan	26	230 14383; 23 17932; 15 Glass	320	Powder	---	75	25	---	268	2.5	---	---	---	---	Good	Black	* N. A.

*(1) Gas torch (2) Plasma arc (3) Oxy-acetylene torch **N. A. = not adaptable to program.

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Furan	27	200 Jet-Kote X-8; 50 TS; 15 Glass	23	.23	1.2	75	30	1.0	265	2.5	---	---	---	5(2)	Good	Black	Uncured in 24 hours.
Furan	28	200 Jet-Kote X-8; 60 TS; 15 Glass	23	.23	---	80	25	1.0	275	2.5	48	15	---	10(2)	Good	Black	Uncured in 24 hours.
Furan	29	180 Jet-Kote X-8; 72 TS; 15 Glass	23	.23	---	73	50	1.0	267	2.5	24	---	Heavy	10(1) 4(2)	Good	Black	Jelled in 2 hours.
Furan	30	180 Jet Kote X-8; 90 TS; 15 Glass	23	.23	1.2	78	25	1.0	285	2.5	6	---	Heavy	10(1) 4(2)	Good	Black	Jelled in 1½ hrs.
Furan	38	180 Jet Kote X-8; 90 TS; 15 Asbestos	Paste	.23	---	75	16	.50	285	2.5	48	---	---	10(2)	Poor	Black	Too viscous to pour.
Furan	45	120 Jet Kote X-8; 60 Catalyst TS; 100 Al_2O_3 Bubbles	Paste	.23	---	75	18	.75	280	2.5	48	---	---	10(2)	Fair	Al_2O_3 bubbles on surface	
Furan	53	85 Furfuryl 16470; 6 Cat. 17932; 125 H_3BO_3; 24 Asbestos	300	Powder	---	77	26	---	240	2.5	---	---	---	---	Fair	Black	Did not set in 24 Hours.
Furan	74	135 Jet Kote X-8; 60 T. S.; 60 Al_2O_3; 10 MgO; 10 Glass mat.	100	1.0	1.2	73	9	---	275	2.5	---	---	---	---	Good	Black	Did not set in 7 hours.
Furan	102	260 16470; 15 17932; 10 Fiberglass	125	Powder	1.2	75	43	1.25	285	2.5	24	---	---	--- 4(2)	Good	Black	
Furan	103	170 Jet Kote X-8; 85 Catalyst TS; 5 Fiberglass; 15 Asbestos	200	.14	---	75	43	.625	275	2.5	24	---	---	--- 10(2)	Good	Black	
Furfuryl Alcohol	1	230 Durez 16470; 26 17932; 8 PTSA; 20 Glass roving	200	Powder	---	80	---	1.1	---	2.5	12	---	---	--- 10(2)	Good	Black	PTSA lumped
Furfuryl Alcohol	2	230 Durez 16470; 26 17932; 8 PTSA	200	Powder	---	80	---	---	---	2.5	---	---	---	--- 5(2)	Good	Black	Started to foam in 6 minutes.
Furfuryl Alcohol	3	230 Durez 16470; 26 17932; 4 PTSA mix; 4 Perlite; 20 Glass	200	Solid	---	---	---	---	---	---	---	---	---	--- 1(2)	---	Black	Foamed in 10 minutes.
Furfuryl Alcohol	4	230 Durez 14383; 26 17932; 4 PTSA mix; 20 Glass roving	---	---	---	---	---	---	---	---	---	---	---	--- 1(2)	---	Black	Heated while pouring; foamed in 15 minutes.
Furfuryl Alcohol	5	230 Durez 16470; 23 17932; 2 PTSA; 10 perlite; 20 Glass roving	---	---	---	---	---	---	---	---	---	---	---	--- 2(2)	---	Black	Started to foam in 12 min.
Furfuryl Alcohol	6	220 16470; 22 17932; 22 Perlite	---	---	---	---	---	---	---	---	---	---	---	---	---	Black	Foamed after 20 minutes.
Furfuryl Alcohol	9	215 Durez 14383; 55 Furane catalyst TS; 15 Glass mat	---	---	---	---	---	---	---	---	---	---	---	---	---	Black	Did not set up in 14 hours.

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Phenolic	87	6" x 6" x 0.55" Coast F-120 Phenolic Pre-fab	---	---	---	---	---	---	56	0.5	---	---	---	--- 0(2)	---	Red	Ruptured and burned through on (2)*
Phenolic	88	6" x 6" x 0.75" Coast F-120 Pre-fab	---	---	---	---	---	---	76	.06	---	---	---	--- 0(2)	---	Red	Panel blew up before 3000°F.
Phenolic	89	6" x 6" x .135 Coast F-120 Pre-fab	---	---	---	---	---	---	131	1.25	---	---	---	--- 0(2)	---	Red	Panel blew up at 3000°F.
Phenolic	158	260 QMC Phenolic; 10 Cat.; 15 Glass	150	.13	---	75	20	.50	285	2.5	3	5	Light	2(3)	Poor	Dark	Very viscous
Polyester	6A	100 Hetron 72; 30 Nylon powder; 3 Sb_2O_3; 2 MEK Peroxide; 20 Glass roving	---	---	---	80	---	.25	---	1.25	5.5	3	Moderate	10(1) 3(2)	Fair	Smooth White	Mixture pours
Polyester	10	160 Hetron 353; 65 Al_2O_3; 15 Glass mat; 32 H_3BO_3; 3 MEK peroxide; 4 Sb_2O_3	---	---	---	---	---	---	---	2.5	---	---	---	--- 10(2)	---	Smooth White	Did not wet well. *Plasma results look promising
Polyester	17	160 Hetron 353; 85 Al_2O_3; 15 H_3BO_3; 4 Sb_2O_3; 3 MEK peroxide; 15 Glass	30	.10	---	80	30	.375	282	2.5	24	---	---	--- 4(2)	Excellent	Smooth White	Did not wet all of glass
Polyester	18	160 Hetron 72; 85 Al_2O_3; 15 H_3BO_3; 4 Sb_2O_3; 3 MEK peroxide; 0.5 Co; 15 Glass	500	.13	---	77	27	.375	282	2.5	12	---	---	--- 3(2)	Fair	Greenish White	Did not wet all of glass.
Polyester	19	160 Hetron 353; 30 H_3BO_3; 4 Sb_2O_3; 3 MEK peroxide; 15 Glass; 85 Al_2O_3	30	.10	---	80	30	.375	297	2.5	24	---	---	--- 6(2)	Good	Smooth Greenish-White	Did not wet all of glass.
Polyester	20	200 Hetron 72; 60 Nylon; 3 Sb_2O_3; 15 Glass; 3 MEK peroxide	145	.10	---	80	30	---	281	2.5	24	---	---	--- 3(2)	Good	White	Slight jell in 30 minutes.
Polyester	35	165 Hetron 353; 65 Al_2O_3; 35 H_3BO_3(C); 4 Sb_2O_3; 3 MEK peroxide; 15 Glass	18.5	.10	---	74	20	0.5	287	2.5	24	---	---	--- 6(2)	Good	---	H_3BO_3 stays in suspension
Polyester	36	165 Hetron 353; 65 SiO_2; 35 H_3BO_3(C); 4 Sb_2O_3; 3 MEK peroxide; 15 Glass	20.5	.10	---	74	20	---	287	2.5	---	---	---	--- 8(2)	Good	Greenish-White	H_3BO_3 stays in suspension
Polyester	37	150 Hetron 353; 115 H_3BO_3(C); 2 Sb_2O_3; 3 MEK peroxide; 15 Glass.	---	.10	---	75	20	0.5	285	2.5	12	---	---	--- 6(2)	Good	Greenish White	----------
Polyester	55	135 Hetron 72; 5 MEK peroxide; 5 Sb_2O_3; 125 Glass filler; 10 Glass mat	350	.10	1.4	75	20	0.5	280	2.5	5.5	---	---	--- 0(2)	Fair	Black	Filler settled to bottom

*(1) = Gas torch (2) = Plasma arc (3) = Oxy-acetylene **N. A. - not adaptable to program

Table 2
Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester	56	135 Hetron 72; 5 MEK peroxide; 5 Sb_2O_3; 125 Al_2O_3 filler; 10 Glass	350	.10	1.3	75	20	0.5	280	2.5	5.5	---	---	--- 7(2)	---	Black	Glass surface blew off.
Polyester	57	135 Hetron 72; 5 MEK peroxide; 5 Sb_2O_3; 125 Al_2O_3 filler; 10 Glass mat.	350	.10	1.4	75	20	0.5	280	2.5	5	---	---	--- 10(2)	Fair	Black	1st cycle surface cracks
Polyester	58	135 Hetron 72; 5 MEK peroxide; 5 Sb_2O_3; 125 Glid-crete filler; 10 Glass mat.	150	.10	1.3	75	20	0.5	280	2.5	5	---	---	--- 5(2)	Fair	White	Cracks appeared on first cycle.
Polyester	59	140 Laminac 4146; 5 Cat.; 125 Glass filler	300	.10	1.4	75	20	0.5	280	2.5	3.5	---	---	--- 6(2)	Fair	Black	----------
Polyester	60	140 Hetron 72; 125 Al_2O_3 filler; 10 Glass mat; 5 MEK peroxide.	350	.10	1.4	75	20	.375	280	2.5	3.5	---	---	--- 4(2)	Fair	Black	----------
Polyester	63	135 Hetron 72; 5 MEK peroxide; 125 Ceramic filler; 5 Sb_2O_3; 10 Glass mat.	550	.10	1.3	75	18	.50	280	2.5	3.75	---	---	--- 5(2)	Fair	Black	
Polyester	64	135 Hetron 72; 5 Sb_2O_3; 5 MEK peroxide; 120 Ceramic filler; 10 Glass mat; 5 CaO	550	.10	1.4	75	20	.50	280	2.5	3.5	---	---	--- 5(2)	Fair	Black	
Polyester	65	140 Laminad 4146; 5 MEK peroxide; 125 Ceramic filler; 10 Glass mat.	500	.10	1.4	75	20	.375	280	2.5	3.5	---	---	--- 6(2)	Fair	Black	
Polyester	66	135 Hetron 72; 5 Sb_2O_3; 120 Ceramic filler; 5 CO_2O_2; 10 Glass mat. 5 MEK peroxide	450	.10	1.4	75	20	.625	280	2.5	3.5	---	---	--- 6(2)	Fair	Black	
Polyester	67	135 Hetron 72; 105 Ceramic filler; 25 Nickel; 10 Glass mat.; 5 MEK peroxide.	400	---	1.4	75	18	.50	280	2.5	3.5	---	---	--- 5(2)	Fair	Black	
Polyester	68	135 Hetron 72; 5 Sb_2O_3; 105 Ceramic filler; 25 Cr filler; 10 Glass mat.; 5 MEK peroxide.	350	.10	1.4	74	18	.50	285	2.5	3.5	---	---	--- 5(2)	Fair	Black	
Polyester	69	140 Laminac 4146; 125 Ceramic filler; 10 Glass mat.; 5 MEK peroxide	550	.10	1.4	74	18	.50	280	2.5	3.5	---	---	--- 5(2)	Fair	Black	
Polyester	70	140 Laminac 4146; 105 Ceramic filler; 25 Cr filler; 10 Glass mat; 5 MEK peroxide	550	.10	---	74	18	.50	285	2.5	3.5	---	---	--- 6(2)	Fair	Black	5 sec. heating cycle @ 3000°F
Polyester	71	140 Laminac 4146; 105 Ceramic filler; 10 Cr; 15 Cu; 10 Glass mat; 5 MEK peroxide	600	.10	1.4	73	15	.50	285	2.5	3.25	---	---	--- 5(2)	Fair	Black	

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester	72	135 Hetron 72; 10 MEK peroxide; 120 Ceramic filler; 5 MgO; 10 Fiberglass mat.	400	.10	1.4	73	9	.50	280	2.5	30	---	---	--- 8(2)	Fair	White	Did not set in 4 hrs at 25°F
Polyester	73	135 Hetron 72; 10 MEK peroxide; 120 Ceramic filler; 5 MgO; 10 Chopped fiberglass	400	.10	1.4	73	9	.50	280	2.5	30	---	---	--- 6(2)	Fair	White	Did not set in 4 hrs at 25°F.
Polyester	78	140 Hetron 72; 10 MEK peroside; 120 Al_2O_3 filler; 10 Glass mat.	500	1	1.4	75	9	.625	280	2.5	30	---	---	--- 3(2)	Fair	White	Resin starved surface
Polyester	79	140 Hetron 72; 10 H_3BO_3; 75 SiO_2; 30 Al_2O_3; 20 Na_2CO_3; 10 MEK peroxide; 10 Glass mat.	200	1	1.4	75	9	.50	295	2.5	22	---	---	--- 5(2)	Good	White	
Polyester	80	140 Hetron 72; 30 Na_2CO_3; 75 SiO_2; 20 Al_2O_3; 10 MEK peroxide; 10 Glass mat.	100	1	1.4	75	9	.50	285	2.5	22	---	---	--- 5(2)	Good	White	
Polyester	81	140 Hetron 72; 30 Na_2CO_3; 100 SiO_2; 10 Glass mat; 5 MEK peroxide	100	1	1.4	74	12	.50	285	2.5	7	---	---	--- 9(2)	Good	White	
Polyester	82	140 Hetron 72; 30 Na_2CO_3; 100 SiO_2; 10 Steel wool; 5 MEK peroxide	100	1	1.4	74	12	1.0	285	2.5	7	---	--- Heavy	--- 1(2)	Good	White	Steel wool irregular; left voids
Polyester	83	135 Laminac 4146; 50 Na_2CO_3; 75 Al_2O_3; 10 Glass mat; 10 MEK peroxide	500	.1	1.3	77	25	.375	280	2.5	1.75	---	--- Moderate	--- 2(2)	Fair	White	
Polyester	84	140 Laminac 4146; 7 Sb_2O_3; 60 Al_2O_3; 55 Boric acid; 10 Glass; 10 MEK peroxide	500	1	1.3	80	43	.375	282	2.5	4	---	---	--- 4(2)	Fair	White	
Polyester	85	140 Hetron 353; 5 Sb_2O_3; 55 H_3BO_3; 60 Al_2O_3; 10 Glass mat; 10 MEK peroxide	100	.1	1.3	82	42	.375	280	2.5	1.75	---	----	--- 7(2)	Good	Yellowish	
Polyester	97	350 Hetron 353; 20 Oncar 23A; 200 H_3BO_3; 5 MEK peroxide	150	.10	1.2	75	43	---	575	5.0	---	---	---	---	Good	White	Torch adjustment ----
Polyester	98	160 Hetron 353; 65 Al_2O_3; 15 Fiberglass; 32 H_3BO_3; 10 Oncar 23; 3 MEK peroxide	90	.10	---	75	43	.50	285	2.5	24	---	--- Light	--- 7(2)	Good	White	----------
Polyester	102	260 16470; 15 17932; 10 Fiberglass	125	Powder	1.2	75	43	1.25	285	2.5	24	---	---	--- 4(2)	Good	White	----------
Polyester	104	150 Hetron 353; 100 H_3BO_3; 10 Oncar 23; 15 Fiberglass; 10 MEK peroxide	100	.10	---	75	43	.50	285	2.5	24	---	---	--- 10(2)	Good	White	----------

*(1) = Gas torch (2) =Plasma arc (3) = Oxy-acetylene torch **N. A. = not adaptable to program.

Table 2
Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester	105	170 Hetron 353; 65 SiO_2; 35 H_3BO_3; 10 Fiberglass; 5 MEK peroxide	90	.10	---	75	45	.50	285	2.5	24	---	---	--- 10(2)	Good	White	----------
Polyester	107	145 Hetron 353; 100 H_3BO_3; 15 Sb_2O_3; 15 Fiberglass; 10 MEK peroxide	60	.10	---	75	35	.625	285	2.5	24	---	---	--- 10(2)	Fair	---	----------
Polyester	108	145 Hetron 353; 100 H_3BO_3; 15 Sb_2O_3; 15 Fiberglass; 10 MEK peroxide	60	0.1	---	75	35	.625	285	2.5	24	---	---	--- 10(2)	Fair	---	----------
Polyester	109	145 Hetron 353; 100 H_3BO_3; 15 Sb_2O_3; 15 Fiberglass; 10 MEK peroxide	60	0.1	---	75	33	.625	285	2.5	24	---	---	--- 10(2)	Fair	---	----------
Polyester	110	135 Hetron 353; 600 Al_2O_3 bubbles; 5 Oncar 23; 5 CO_2O_2; 5 MEK peroxide; 15 Glass mat.	45-50	0.1	---	74	30	.600	285	2.5	24	---	---	2(1) ---	Fair	Black	Criteria for high energy torch
Polyester	111	135 Hetron 353; 60 H_3BO_3; 60 Al_2O_3 bubbles; 5 Oncar 23; 5 CO_2O_2; 5 MEK peroxide; 15 Glass mat.	45-50	0.1	---	74	31	.625	285	2.5	4.5	---	---	--- 17(2)	Fair	Black	
Polyester	112	145 Hetron 353; 100 H_3BO_3; 13 Sb_2O_3; 15 Fiberglass; 10 MEK peroxide	30	0.1	---	75	31	.625	283	2.5	24	---	---	3(1) ---	Good	White	Torch adjustment
Polyester	113	145 Hetron 353; 100 H_3BO_3; 15 Oncar 23A; 15 Fiberglass; 10 MEK peroxide	30	0.1	---	75	31	.625	285	2.5	4.75	---	---	--- 20(2)	Good	---	----------
Polyester	114	160 Hetron 353; 115 H_3BO_3; 6 Glass	27-30	0.1	---	74	30	.750	285	2.5	24	5-15	Moderate	3(3)	Good	White	(3) distance - 8"
Polyester	115	160 Hetron 353; 115 H_3BO_3; 6 Glass; 4 MEK peroxide	27-30	0.1	---	74	30	.750	285	2.5	24	3-5	Moderate	4(3)	Good	White	(3) distance - 8"
Polyester	116	160 Hetron 353; 115 H_3BO_3; 6 Glass; 4 MEK peroxide	27-30	0.1	---	74	30	.750	285	2.5	24	3-5	Moderate	3(3)	Good	White	(3) distance - 8"
Polyester	117	160 Hetron 353; 115 H_3BO_3; 6 Glass; 4 MEK peroxide	27-30	0.1	---	74	30	.750	285	2.5	24	3-5	Moderate	3(3)	Good	White	(3) distance - 8"
Polyester	118	160 Hetron 353; 115 H_3BO_3; 6 Glass; 4 MEK peroxide	27-30	0.1	---	74	30	.750	285	2.5	24	3-5	Moderate	4(3)	Good	White	(3) distance - 8"
Polyester	119	160 Hetron 353; 90 H_3BO_3; 15 Oncar 23A; 15 Glass; 5 MEK peroxide	22-23	0.1	---	75	35	.625	285	2.5	24	1-2	Light	7(3)	Good	White	(3) distance - 8"

*(1) = Gas torch (2) = Plasma arc (3) = Oxy-acetylene torch ** N. A. = not adaptable to program

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester	120	160 Hetron 353; 90 H_3BO_3; 15 Oncar 23A; 15 Glass; 5 MEK peroxide	22-23	0.1	---	75	35	.625	285	2.5	24	1-3	Light	7(3)	Good	White	(3) distance - 8"
Polyester	121	160 Hetron 353; 100 H_3BO_3; 15 Oncar 23A; 6 Quartz; 4 MEK peroxide	40-50	0.1	---	75	35	.625	285	2.5	24	1-2	Light	5(3)	Good	White	(3) distance - 7"
Polyester	122	160 Hetron 353; 100 H_3BO_3; 15 Oncar 23A; 6 Quartz; 4 MEK peroxide	40-50	0.1	---	75	35	.625	285	2.5	24	1-2	Light	5(3)	Good	White	(3) distance - 7"
Polyester	123	160 Hetron 353; 100 H_3BO_3; 15 Oncar 23A; 6 Quartz; 4 MEK peroxide	40-50	0.1	---	75	35	.625	285	2.5	24	1-2	Light	5(3)	Good	White	(3) distance - 7"
Polyester	124	160 Hetron 353; 90 H_3BO_3; 15 Oncar 23A; 15 Glass quartz; 5 Mek peroxide	30	0.1	---	75	20	.375	285	2.5	6	3-10	Light	6(3)	Good	White	(3) distance - 4"
Polyester	125	160 Hetron 353; 90 H_3BO_3; 15 Oncar 23A; 15 Glass quartz; 5 MEK peroxide	30	0.1	---	75	20	.375	---	2.5	6	3-15	Light	4(3)	Good	White	(3) distance - 3"
Polyester	126	160 Hetron 353; 90 H_3BO_3; 15 Oncar 23A; 15 Asbestos; 5 MEK peroxide	Paste	0.1	---	75	20	.375	285	2.5	0.5	3-15	Moderate	11(3)	Poor	White	(3) distance - 7"
Polyester	127	160 Hetron 353; 100 H_3BO_3; 15 Oncar 23A; 5 Asbestos; 5 MEK peroxide	1000	0.1	---	75	28	.375	285	2.5	24	3-10	Moderate	7(3)	Poor	White	(3) distance - 7"
Polyester	128	160 Hetron 353; 100 H_3BO_3; 15 Sb_2O_3; 6 Glass; 4 MEK peroxide	30-50	0.1	---	72	22	.375	285	2.5	4	1-6	Light	5(3)	Good	White	(3) distance - 4"
Polyester	129	160 Hetron 353; 100 H_3BO_3; 15 Sb_2O_3; 6 Glass; 4 MEK peroxide	30-50	0.1	---	72	22	.375	285	2.5	4	1-6	Light	5(3)	Good	White	(3) distance - 4"
Polyester	130	160 Hetron 353; 100 H_3BO_3, 15 Sb_2O_3; 6 Glass; 4 MEK peroxide	30-50	0.1	---	72	22	.375	285	2.5	4	1-8	Light	5(3)	Good	White	(3) distance - 4"
Polyester	131	160 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 15 Glass; 5 MEK peroxide	30-50	0.1	---	75	25	.375	285	2.5	4	1-8	Light	5(3)	Good	White	(3) distance - 4"
Polyester	132	160 Hetron 353; 90 H_3BO_3; 15 Glass; 5 MEK peroxide	30-50	0.1	---	75	25	.375	25	2.5	4	1-8	Light	5(3)	Good	White	(3) distance - 4"
Polyester	133	160 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 15 Glass; 5 MEK peroxide	30-50	0.1	---	75	25	.375	285	2.5	4	1-8	Light	5(3)	Good	White	(3) distance - 4"

*(1) = Gas torch (2) = Plasma arc (3) = Oxy-acetylene torch **N.A. = not adaptable to program

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester	134	160 Hetron 353; 80 H_3BO_3; 15 Oncar 23A; 25 Milled fiberglass; 5 MEK peroxide	Paste	0.1	---	75	20	.375	285	2.5	8	3-15	Moderate	5(3)	Poor	White	(3) distance - 4"
Polyester	135	160 Hetron 353; 85 H_3PO_3; 15 Sb_2O_3; 15 Milled fiberglass; 5 Quartz roving; 5 MEK peroxide	200	0.1	---	75	25	.375	285	2.5	2.67	2-8	Light	6(3)	Poor	White	(3) distance - 4"
Polyester	142	160 Hetron 353; 40 Powd quartz; 65 H_3BO_3, 15 Sb_2O_3; 5 MEK	40-45	0.1	---	72	22	.375	285	2.5	1.5	1-10	Moderate	5(3)	Good	White	(3) distance - 4"
Polyester	149	210 Hetron 353; 40 H_3BO_3; 15 Asbestos fiber; 15 Sb_2O_3; 5 MEK peroxide	Paste	0.1	---	75	30	.375	285	2.5	1.25	1-5	Light	4(3)	Poor	White	(3) distance - 4"
Polyester	150	160 Hetron 353; 100 H_3BO_3; 15 Sb_2O_3; 5 Asbestos; 5 MEK peroxide	1000	0.1	---	75	30	.375	285	2.5	24	3	Light	4(3)	Poor	White	(3) distance - 4"
Polyester	151	160 Hetron 353; 100 Ferro frit; 20 Sb_2O_3; 5 MEK peroxide	30	0.1	---	75	22	.375	285	2.5	2.5	3-6	Moderate	2(3)	Good	Black	(3) distance - 4" Frit tends to settle
Polyester	152	170 Hetron 353; 50 H_3BO_3; 50 Ferro frit; 8 Sb_2O_3; 2 Asbestos; 5 MEK peroxide	20-30	0.1	---	75	20	.375	285	2.5	4.0	3-7	Moderate	3(3)	Good	Black	(3) distance - 4"
Polyester	158	260 QMC Phenolic; 10 Cat.; 15 Glass	150	0.13	---	75	20	.500	285	2.5	3.0	5	Light	2(3)	Poor	Dark	(3) distance - 4" very viscous.
Polyester	159	320 Hetron 353; 180 H_3BO_3; 30 Sb_2O_3; 30 Fiberglass; 10 Cat.	45	0.13	---	50	40	.625	370	5.0	3.0	3	Moderate	8(3)	Good	White	(3) distance - 3.6"
Polyester	160	320 Hetron 353; 180 H_3BO_3; 30 Sb_2O_3; 30 Fiberglass; 10 Cat.	30	0.13	---	73	35	.625	370	5.0	3.0	1-10	Light	10(3)	Good	White	(3) distance - 3.6"
Polyester	161	180 Hetron 353; 70 H_3BO_3; 15 Glass; 15 Sb_2O_3; 5 MEK peroxide	50-60	0.13	---	75	30	.375	285	2.5	48	1-7	Light	4(3)	Good	White	(3) distance - 4"
Polyester	162	160 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 15 Quartz; 5 MEK peroxide	35-40	0.13	---	73	43	.375	285	2.5	5.75	1-7	Light	5(3)	Good	White	(3) distance - 4"
Polyester	163	160 Hetron 353; 80 H_3BO_3; 10 C_2O_2; 15 Sb_2O_3; 15 Fiberglass; 5 MEK peroxide	35-40	0.13	---	73	42	.375	285	2.5	5.0	3	Light	3(3)	Good	Black	(3) distance - 4"
Polyester	164	165 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 10 Quartz; 5 MEK peroxide	35	0.13	---	73	42	---	285	2.5	---	1-5	Light	5(3)	Good	White	(3) distance - 4"

*(1) = Gas torch (2) = Plasma arc (3) = Oxy-acetylene torch **N. A. = not adaptable to program

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester	165	180 Hetron 353; 50 Asbestos; 30 H_3BO_3; 15 Sb_2O_3; 5 Quartz; 5 MEK peroxide	40-50	0.13	---	73	40	.375	285	2.5	5.0	2-8	Light	3(3)	Fair	White	(3) distance - 4"
Polyester	166	180 Hetron 353; 70 Graphite; 15 Glass; 15 Sb_2O_3; 5 MEK peroxide	50-60	0.13	---	75	50	.375	285	2.5	5.0	25	Heavy	2(3)	Fair	Black	(3) distance - 4"
Polyester	179	160 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 15 Fiberglass; 5 Cat.	---	---	---	---	---	.250	---	2.5	---	2-15	Moderate	3(3)	---	Pink	(3) distance - 7"
Polyester	174	160 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 30 Glass roving; 5 MEK peroxide	---	0.54	---	80	30	0.32	285	2.5	4	2	Moderate	10(3)	Excellent	White	(3) distance - 7.5"
Polyester	175	180 Hetron 353; 70 H_3BO_3; 15 Sb_2O_3; 15 Glass roving; 5 MEK peroxide	---	0.54	---	78	30	.310	285	2.5	4	1-8	Moderate	6(3)	Good	---	(3) distance - 7.5"
Polyester	176	195 Hetron 353; 55 H_3BO_3; 15 Sb_2O_3; 15 Glass; 5 MEK peroxide	---	---	---	78	35	.32	285	2.5	4	1-8	Moderate	6(3)	---	White	(3) distance - 7.5"
Polyester	177	160 Hetron 353; 90 H_3BO_3; 15 Sb_2O_3; 15 Glass fiber; 5 MEK peroxide	---	---	---	78	35	---	285	---	4	1-8	Med. Heavy	11(3)	Excellent	---	(3) distance - 7.5"
Polyester	178	210 Hetron 353; 40 H_3BO_3; 15 Sb_2O_3; 15 Glass; 5 MEK peroxide	---	---	---	---	---	.32	285	2.5	---	1-	Light Mod.	5(3)	---	White	(3) distance - 7.5"
Polyester	114A	160 Hetron 353; 115 H_3BO_3; 6 Glass roving; 4 MEK peroxide	---	---	---	75	31	---	285	2.5	---	---	---	---	Good	White	Cont. exposure
Polyester	115A	160 Hetron 353; 115 H_3BO_3, 6 Glass; 4 MEK peroxide	---	---	---	75	31	---	285	2.5	3.67	---	---	---	---	White	Cont. exposure
Polyester	116A	240 Hetron 353; 25 Oncar 23A; 15 Glass roving; 5 MEK peroxide	---	---	---	74	31	---	285	2.5	---	---	---	---	Good	White	----------
Polyester	117A	240 Hetron 353; 25 Oncar 23A; 15 Glass roving; 5 MEK peroxide	---	---	---	74	31	---	285	2.5	---	---	---	5(2)	Good	White	----------
Polyester	118A	180 Hetron 353; 72 LiF; 15 Glass; 10 MEK peroxide; 8 Oncar 23A	120	Oil	---	75	31	---	285	2.5	---	---	---	--- 14(2)	Fair	White	

*(1) - Gas torch (2) - Plasma arc (3) = Oxy-acrtylene torch ** N. A. = not adaptable to program

Table 2

Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Polyester Ceramic	92	110 Siroc #1; 11.5 Siroc #2; 11.5 H_2O; 10 Glass mat; 90 Hetron 353; 45 H_3BO_3; 5 MEK peroxide	50-100	---	1.2	80	40	1.0	283	2.5	28	---	---	10(2)	Good	Yellowish	
	93	Same as above minus glass mat	50-100	---	1.2	80	35	1.0	288	2.5	4.25	---	---	10(2)	Good	Yellowish	
Polyimide	46	Dupont Pyne - M. L. film - 7g.	---	Prefab	---	---	---	.006	7	.05	---	0	Light	1(1)	---	Brown coated fabric	N. A. **
Polyimide	47	Dupont H film		Prefab	---	---	---	.0025	2	.015		0	None	1(1)	---	Amber film	N. A. **
Polyimide	91	Polymer SP Pre-fab	---	---	---	---	---	---	---	2.2	---	---	---	--- 4(2)	---	Brown	N. A. **
Polyurethane	17A	Prefab material	---	---	1.1	80	---	0.5	---	2.5	16	---	Light	1(1)	Good	Black	N.A. **
	106	110 U. S. 104-R; 80 US-104-C; 15 Glass	1.5	0.1	---	75	45	1.0	205	1.8	24 15	---	---	--- 1(2)	Good	Clear	
Rubber	52	Viton A rubber	---	Prefab	---	---	---	---	---	0.3	---	0	Med. Heavy	5(1)	---	Black	N. A. **
Rubber	95	Neoprene impregnated asbestos cloth - Style 89-aluminized	---	---	---	---	---	.045	---	0.3	---	---	---	6(2)	---	Silver	----------
Rubber	96	Same as above	---	---	---	---	---	.145	---	0.1	---	---	---	--- 10(2)	---	Silver	----------
Sandwich	48	Al skins; paper cone; urethane foam; adhesive	---	Prefab	---	---	---	2.5	549	0.1	---	---	---	2(1)	---	White paint	N. A. **
Sandwich	50	Glass reinforced urethane skins; urethane foam	---	---	---	---	---	2.88	68	2.5	---	---	---	2(1)	---	---	N. A. **
Silicone	18A	245 Q-2-0103 Dow Corning; 24.5 Cat.; 14 Glass	Thick paste	Paste	1.55	80	---	---	---	2.5	12	15	Light	3(1)	Poor	Tan	N. A. **
Silicone	39	Dow Corning-2106 Laminate	---	Prefab	---	---	---	.125	139	1.25	---	---	---	9(2)	---	White	----------
Silicone	40	Dow Corning-Q-90-03-½	Prefab	Prefab	---	---	---	.125	113	1.0	---	1	Light	4(1) 1(2)	---	Red	----------

*(1) = Gas torch (2) = Plasma arc (3) = Oxy-acetylene torch ** N. A. = not adaptable to program

Table 2
Summary of Flame-Erosion Screening Test Data (Continued)

Material Group	Sample No.	Material - Composition (grams)	Viscosity (Poise) Base	Viscosity (Poise) Accel.	Spec. Grav. of Base	Ambient Temp. (°F.)	Ambient Hum. (%)	Thickness (In.)	Total Mix Wt. (gram)	Density (lbs. per ft.^{2})	Mix to Test Time (hrs.)	Burn Time in Sec.	Smoke	Cycles *	Handling Prop	Appearance	Remarks * **
Silicone	41	Dow Corning Silastic 6535	Pre-fab	Pre-fab	---	---	---	.016	14.5	0.1	---	0	Light	2(1)	---	Red	A one shot system
Silicone	90	Dow Corning 302 Pre-fab	---	---	---	---	---	---	50	1.25	---	---	---	2(2)	---	Red	----------
Silicone	167	250 RTV 589; 25 DC-200; 1.2 502 Cat.; 7.8 Glass	130	0.15	---	75	35	.30	284	2.5	336	7	Light	10(3)	Poor	Red	Still tacky after 6 hrs.
Teflon	42	6"x6"x½" Teflon	Pre-fab	Pre-fab	---	---	---	0.5	654	5.74	---	---	---	5(2)	---	White	
Teflon	44	6"x6"x1/32" Teflon Asbestos pad	Pre-fab	Pre-fab	---	---	---	---	---	0.35	---	15	Light	1(1)	---	Slate	A one shot system
Teflon	51	6"x6"x1/16" Teflon felt pad	---	Pre-fab	---	---	---	---	---	.06	---	---	---	1(1)	---	Brown	N. A. **

*(1) - Gas torch (2) - Plasma arc (3) - Oxy-acetylene torch ** N. A. = not adaptable to program

APPENDIX A

SOIL DEPOSITS, TYPES, CHARACTERISTICS, OCCURRENCE AND PROBLEM AREAS RELATED TO RAPID SITE PREPARATION*

The nature of rapidly prepared landing sites for VTOL aircraft in close support of tactical military operations dictates maximum use of ground surface materials as they exist. This results from the absence of facilities and time to import, manipulate or otherwise modify surface soils at such sites. The following brief review of surface and near-surface soils of the earth pertains to this problem.

The characteristics of soil deposits are influenced by the manner in which they were and are formed; that is, residual or transported. Upland, gently rolling and well drained, terrain is characteristic of residual deposits whose surface soils may vary from the highly weathered and leached types on gentle slopes to unweathered parent materials on steep slopes. The transported deposits are characteristic of alluvial plains and relatively flat lands which generally are not as well drained. They are the reworked materials that have experienced both mechanical and chemical weathering and have been leached to limited extent.

Soils, from an engineering point of view, are divided into two broad categories; namely, coarse and fine grained. The dividing criterion is the 0.074 mm (No. 200 mesh sieve size) particle size with $> 50\%$ defining the coarse and $< 50\%$ the fine category. Each category is subdivided, by the Unified Soil Classification System used by Engineers, into several groups that can be readily identified by either field or laboratory techniques. The coarse grained category, ranging from gravels to fine sands (+ 0.074 mm minimum particle size), is grouped on a textural basis. The fine grained category ranges from silts (minus 0.074 mm maximum particle size) to highly plastic clays, that are grouped according to their plasticity or cohesive characteristics. The categories and groups, along with their identifying characteristics, are illustrated by Figure 1.

The untilled surface and near-surface soils of both types of deposits occur predominantly as combinations of these categories, such as sandy gravels, silty sands or silty clays. This is due to the combined influence of weathering, leaching and aeolian erosion. The tilling of surface soils upsets the natural processes and results in a trend toward closer conformance with the specific grouping. This influence on the soil structure, in-situ strength and other factors is treated later in this report, for it is significant.

*From information prepared by Spencer J. Buchanan and Associates, Inc., Consulting Engineers, Bryan, Texas.

			SYMBOL		
COARSE – GRAINED SOILS MORE THAN HALF OF MATERIAL IS LARGER THAN NO. 200 SIEVE. (THE NO. 200 SIEVE SIZE IS ABOUT THE SMALLEST PARTICLE VISIBLE TO THE NAKED EYE)	GRAVELS MORE THAN HALF OF COARSE FRACTION IS LARGER THAN NO. 4 SIEVE SIZE (1/4) IN.	CLEAN GRAVELS (LITTLE OR NO FINES)	GW	UNUSUAL SOIL, RARELY OCCURRING ON GROUND SURFACE IN NATURE. VERY STABLE WET ANL DRY STATES.	GW — GRAVEL WELL GRADED.
			GP	SAME AS ABOVE	GP — GRAVEL POORLY GRADED.
		GRAVELS WITH FINES (APPRECIABLE AMT OF FINES)	GM	SAME AS ABOVE. USED FOR FARM ROAD SURFACING.	GM — GRAVEL WITH SILT. (SILTY GRAVEL)
			GC	SAME AS ABOVE, ALSO USED FOR FARM ROAD SURFACING.	GC — GRAVEL WITH CLAYS. (CLAYEY GRAVELS)
	SANDS MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE (1/4 IN.)	CLEAN SANDS (LITTLE OR NO FINES)	SW	UNUSUAL SOIL, RARELY OCCURRING IN NATURE.	SW — SANDS WELL GRADED.
			SP	COMMON DESERT, SAND BARS IN RIVERS AND BEACH SOILS.	SP — SANDS POORLY GRADED.
		SANDS WITH FINES (APPRECIABLE AMT OF FINES	SM	COMMON FLOOD PLAIN SOILS IN BROAD VALLEYS.	SM — SAND WITH SILTS. (SILTY SANDS)
			SC	COMMON FLOOD PLAIN SOILS IN OLD AND BROAD VALLEYS.	SC — SAND WITH CLAY (CLAYEY SANDS)
FINE – GRAINED SOILS MORE THAN HALF OF MATERIALS SMALLER THAN NO. 200 SIEVE. (THE NO. 200 SIEVE SIZE IS ABOUT	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50		ML	TYPICAL FLOOD PLAIN SOILS IN BROAD RIVER VALLEYS.	ML — INORGANIC SILTS AND VERY FINE SANDS.
			CL	LOW TO MEDIUM PLASTICITY SOILS TYPICAL OF TEMPERATE ZONE.	CL — INORGANIC CLAYS, SANDY OR GRAVELLY CLAYS.
			OL	UNUSUAL BUT TYPICAL OF FREQUENTLY FLOODED AREAS ADJACENT TO GEOLOGICALLY OLD RIVERS.	OL — ORGANIC SILTS AND SILT CLAYS.
	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50		MH	UNUSUAL DIATOMACEOUS SOILS RARELY OCCURRING.	MH — INORGANIC SILTS.
			CH	HIGHLY PLASTIC SOILS TYPICAL OF TUNDRA AND TROPICAL AREAS.	CH — INORGANIC CLAYS.
			OH	TYPICAL ORGANIC SOILS, MARSHY AND DELTAIC AREAS.	OH — ORGANIC CLAYS.

Figure 1 Soil Classifications

The geographical occurrence of basic soil categories is a function primarily of climate, terrain features and transporting agents. Review of the indicated factors is treated by climatic zones as follows:

a. ARTIC AND ANTARCTIC ZONES. The permanent or near permanent frozen state of the surface materials within these zones precludes action of normal weathering and transporting agents and their consequent soil forming processes. Exception occurs in mountainous terrain where glaciers move down valleys tearing, gouging and abrading the parent rocks to form the coarse grained soils deposited as moraines over vast areas. In the instance of tundras or flat-land areas bordering the permanent ice caps, the fine grained clays predominate. During the summer season many areas are marsh-like whereas during the winter they are frozen. In summary, during the summer season the soil masses are characterized as saturated clay-like soils in tundra and flat-land areas, or as coarse grained soils in moraine areas, both of which types become frozen during winter seasons.

b. TEMPERATE ZONE. The seasonal temperature and rainfall variations combine to make the agents of weathering and transportation fully active for soil production. Accordingly, typical residual and transported deposits of fine grained surface soils predominate in the sandy- or silty-clay category. Exceptions of significance occur in desert, mountainous, moraine and similar areas where sands or heterogeneous soils may predominate. The condition, as opposed to the kind, of surface soils will generally be a function of the rainfall within the zone, for, except at shore lines, the normal ground water can be anticipated to be 10 or more feet beneath the surface. A moderate state of stability may be expected. In summary, the representative surface soil of the temperate zone is a sandy clay in a relatively stable condition.

c. TROPICAL ZONE. The relatively large annual rainfall, continued warm to hot weather and heavy vegetative growth have produced the acetic lateritic clays containing iron and alumina. The extreme weathering, characteristic of this zone, has caused the parent rocks to decay rapidly. Again, there are exceptional areas where the surface soils do not conform to the indicated pattern. Stability of the surface soils will vary with the terrain, in that sloping terrain normally provides good drainage and stability, whereas low lying flat-land areas have poor drainage and low stability. As in the discussion for soils in other zones, exceptional areas will differ from the typical. For example, in broad valleys of geologically old rivers, traces of extensive sand deposits are to be expected as the result of river action. In summary, the representative surface soil of the tropic zone is the lateritic clay in a moderate state of stability.

Satisfactory use of the typical surface soils in each climatic zone, as pertains to rapidly prepared landing sites for VTOL aircraft, will depend primarily on adaptability to exhaust blast effect (both heat and velocity) and wheel loads of the aircraft. Two exhaust blast effects are of major concern; namely, high temperature and velocity. The high temperature of the blast will serve to dry the surface soil and thereby improve its ability to support wheel loads. However, soil is a great insulating material with heat absorption capacity of about 50 BTU per square foot per minute when in an average natural state. Therefore, the high temperature can be expected to

penetrate the soil to a very limited degree due to its natural insulating properties. Soil in untilled areas, except in deserts, normally supports vegetative growth. Accordingly the anticipated 3000°F temperature of the core of the blast and decreasing to about 200°F within a radius of about 15 ft., should ignite and consume the growth, creating a serious hazard upon landing. The high velocity of the blast will in turn accentuate the burning. The ashes and burned debris shoud create a serious hazard to jet engine operations. Thus the primary effect of heat on the properties of surface soil would not be significant, whereas the effect on vegetative cover would be significant, requiring either a protective cover or prior removal.

The erosion effect due to velocity of the exhaust blast is considered to be tragic. Reportedly, the maximum blast velocity at a radius of 1.5 ft. is approximately 2929 ft./sec. (2040 mph) decreasing to 680 mph at 10 ft. radius and 68 mph at 100 ft. radius. The striking feature of such a blast is that it impinges at the landing surface and must travel close thereto. Wind velocities in nature are normally measured at some distance above the ground surface. Thus the frictional influence of grasses, weeds, shrubs and trees, coupled with irregularities in the natural ground surface, tend to reduce the surface velocity to nominal degree. Nevertheless surface erosion can become noticeable at velocities in the order of 50 mph. It may be recalled in the tropical and temperate zones the typical soils are clay-like, and as such possess cohesion which binds the particles together to resist wind erosion. However, it cannot be seen how surface soils could possibly resist the erosive action created within the 100 ft. radius area. Therefore a protective medium within the indicated area is indicated to be imperative.

The stability and nature of untilled surface soils of the climatic zones reviewed above are judged to be adequate to support the wheel loads of VTOL aircraft under consideration. A typical VTOL aircraft might utilize closely spaced dual tires for each of the main landing gear, inflated to tire pressures of 35 psi and bearing a load of about 18,000 pounds. These data are comparable with the much used C-47 aircraft except that the tire pressure is only 60 per cent of the C-47. Since the C-47 aircraft has operated successfully from turfed airfields and unprepared areas throughout the world, it would appear that VTOL aircraft can do likewise. The shear strength required to resist the stress of such aircraft is computed to be 3 to 5 psi, which is a rather low value. The tire pressures of cross country Army vehicles are interesting by comparison. For example, the jeep uses a tire inflation pressure of 35 psi and the combat 6 by 6 trucks use 60 to 70 psi. Accordingly by theoretical analysis and experience, it is evident that the proposed aircraft can land and move over most surface soils under normal conditions.

The stability of fine grained soils is strongly influenced by their degree of saturation with water. Accordingly, marsh, low lying deltaic and similar excessively wet areas, should be avoided due to the low soil strengths. Similar low strengths prevail in surface soils during extended periods of rainfall, especially in broad flat valleys. However, by seeking rapidly prepared sites on gentle sloping well drained lands possessing reasonable stability, reasonable results should be obtained. Although precipitation may occur, vertical landings on wet surface soils, wherein the aircraft tires sink into the surface some three to six inches to secure support, do not appear to be of serious consequence.

The stability of coarse grained soils beneath aircraft wheels is not particularly sensitive to degrees of saturation. They derive their stability from intergranular friction rather than cohesion. Precipitation on such land areas normally penetrates and drains vertically downward. Accordingly, the downward movement of infiltering water creates seepage pressures which increase the intergranular friction and stability. Land areas whose surface soils are in this category are considered to be limited. Unfortunately, they are highly erodible by blast action, not possessing the cohesion of clays to bond the particles together, thus dictating a high degree of erosion control.

In summary, the problem areas resulting from heat, erosion, wheel loads and soil bearing capacities are as follows:

a. Heat. Insulating ability and low heat absorbability of soils combine to indicate the anticipated heat range may have limited effect upon both condition and stability of surface soils, except those containing significant organic matter or vegetative growth. The organic matter would be ignited by the heat and fanned by the blast to produce damaging debris to aircraft engines.

b. Erosion. Engine blast velocities are indicated to be of the order of 2000 mph at r = 1.5 ft.; 1000 mph at r = 4 ft. and 68 mph at r = 100 ft. radiating from the point of application and at the ground surface. The effect on surface soils of all categories should be devastating in that, for the central area, any soil would be eroded with explosive intensity by such velocities.

c. Soil Bearing Capabilities for Indicated Wheel Loads and Tire Pressures. The general nature and condition of surface soils of untilled lands are considered capable of supporting the subject aircraft during dry to nominal periods of rainfall. Exceptions exist such as in the instance of protracted periods of excessive rainfall, or in low lying swamp areas of flood plains.

DISCUSSION OF TYPICAL SOIL TYPES - CLIMATIC ZONES

To aid your Applied Research and Development Staff in evaluation of representative surface soils of the three climatic zones of the earth, the following discussion is presented.

a. Arctic and Antarctic Zones. The typical soils of these zones are considered to be predominantly either the well rounded gravels or the highly plastic clays. The gravel is representative of the glacial outwash plains forming the tundra areas. The characteristics of each of these soils are treated as follows:

1. Glacial Outwash Gravel. The basic minerals of the gravel are those characteristic of the magma forming the parent crust of the earth. Thus the particles are hard abraded rock, worn to a well rounded condition by glacial transport. The surface of such material is eroded and leached of the fine gravel, sand and silt, leaving an unbonded billiard-ball surface. Little or no vegetative growth thrives on such surface material. It drains rapidly by infiltration because of relatively high

permeability. Heat will have no significant effect on the surface material except that the rapidly applied high temperature would probably cause surface splintering of the stones, like exfoliation. Erosion will be extensive due to excessive exhaust velocities because the soil particles are unbonded in nature. However such material could be bonded by surface application of heat resistant material within the +50 mph velocity zone. Wheel loads and tire pressures would be of little concern on this soil. Suggested representative material for simulated laboratory testing is one-inch maximum size well rounded basaltic gravel such as obtained from the vicinity of Knippa, Texas.

2. Tundra Clay. This is a Na-ion highly plastic clay of marine origin in a wet and undrained state. Subject soil should have Atterberg Liquid Limits of 100 ± and Plasticity Indices of 50 ± and have natural moisture contents of 75 to 90 percent. Heavy vegetative growth is normally supported in summer season on such soil, whereas in the winter season both vegetation and surface soil are frozen. The soil is a very impervious material that water would be slow to penetrate or leave. Heat in excess of 180°±F, would desiccate vegetative growth and, at about 500°±F, would ignite and burn furiously under engine exhaust blast. Erosion by engine exhaust blast in excess of approximately 200 mph velocity is estimated to be violent, and would involve two phases: (a) small amount of sandy or silt-like soil occurs at the ground surface that would be blown outward from the aircraft as a cloud like that created by a helicopter in landing on a natural soil; and (b) the engine exhaust blast as the aircraft approached the landing surface would rip the in-place soil loose to a depth of several feet like a giant stream of water in placer mining operations, sprayed radially by the high velocity blast to add materially to the cloud. Wheel loads and tire pressures previously mentioned should penetrate such soils in ruts estimated to be three to eight inches in depth. Suggested representative material is the Beaumont clay of the Texas and Louisiana Coastal Plains.

b. Temperate Zone. The typical surface and near-surface soils in this zone are considered to be a sandy clay of medium to low plasticity (Atterberg Liquid Limit 35 - Plasticity Index 20) containing a natural moisture content in summer of 10 to 20 per cent and in winter of 15 to 25 per cent. Selection of site for rapid preparation should be made in an untilled land area. Except at the shore line, ground water would be expected to be 10 or more feet beneath the ground surface so that stability of the surface soils would be adequate to support the proposed aircraft. Heat effect would be of no consequence except as producing accelerated combustion of surface vegetation. Erosion of this material by winds less than 50 ± mph is not normally experienced due to the cohesion possessed; however, as reviewed for the soils of the tundra areas of the Artic Zone, protection in the form of a noncombustible membrane is considered imperative for the immediate region of the high temperature-blast velocity beneath the engine exhausts, and for a radial distance therefrom to the point of dissipation of heat to less than 180°±F and blast velocity to less than 50 ± mph. Wheel support is expected to be satisfactory from this category of soil. Representative samples of this soil are available from Spencer J. Buchanan and Associates, Inc.

c. Tropical Zone. Typical soils in this zone are the lateritic clays ranging from medium to high plasticity (Atterberg Liquid Limit 50+ and Plasticity Indices 25+) existing principally as residual deposits. The natural moisture content of surface or near-surface soils may be expected to be of the order of 20 to 30 per cent. This relatively high moisture is attributed to relatively heavy vegetative growth which serves to retard both surface runoff and evaporation or desiccation. The nature of this typical soil and its general condition indicate marginal stability may be expected during the rainy season but moderate stability in the dry season. Heat effect on the subject material, especially for short time intervals (less than several minutes), would be insignificant insofar as the soil is concerned but as regards the vegetation, combustion can be expected for temperatures in excess of 200°±F. Erosion of the lateritic clays by blast velocities up to 100 mph would be minimal; however, erosion of vegetative cover by blast velocities of 50 mph probably would be excessive. Wheel loads and tire pressures of the indicated magnitude should be able to move with limited difficulty over such surface soils with moderate rutting. Suggested soils representative of the Beaumont Clay common to the Texas and Louisiana Coastal Plains could be used for testing.

Recapitulation of the typical soil types for the three climatic zones shows the following:

a. Arctic and Antarctic Zones. Gravels (GP) for the glacial outwash plains and the highly plastic clay (CH) for the tundra land areas.

b. Temperate Zones. Silty or sandy clays (CL) are the predominant surface soils of these zones.

c. Tropical Zone. Lateritic highly plastic (CH) clays are the predominant typical soils in this zone.

DISCUSSION OF REPRESENTATIVE SOILS AND FEASIBLE MEANS OF STABILIZATION

The basic characteristics of the four surface soils, representative of the climatic zones, and their relation to the problem at hand are summarized as follows:

a. Gravels. This is an unbound material, with a billiard-ball surface, very pervious, nude of vegetation and occurs in a very stable condition with large bearing capacity. Arctic winds and the moderate velocity outwash from melting glaciers have eroded the smaller gravels and sands from the exposed surface. Because of the unbonded well rounded particles and rough surface, such areas would be seriously eroded by engine exhaust blasts in the high velocity (+50 mph) zones. The flying stones would probably do terrific damage to the aircraft. In addition the high temperatures common to the high velocity blast zones would cause spontaneous fragmentation of stones that would accentuate damage to the metal surfaces of the aircraft. The open texture of the material and its perviousness would combine to make it receptive to some form of grout or cementitious heat resistant ground cover

to bond the surface particles and resist aeolian erosion and thus form an acceptable landing surface.

b. Highly Plastic Clays of the Tundra Areas and Tropical Zone. This material is a tightly bound cohesive material, in a moist state, very impervious, supports rank vegetative cover, and probably would experience terrific erosion within the immediate area of the high temperature and velocity zone of the exhaust blast. The high temperature blast can be expected to ignite vegetative growth unless this material can be disposed of as a part of the site preparation, as discussed later. It has been observed generally that in untilled areas a thin mantle (1/16 to 1/4 inch) of sand or silt-like soil will occur at the undisturbed ground surface of highly plastic soils, such as those being described. Further, it has been my experience with traveling in helicopters the prop wash, when landing or taking off, causes erosion of this thin top mantle of unbonded non-cohesive soil to form a dust cloud which envelopes the area. If this analysis is correct, then it occurs that a chemical spray could quickly penetrate such material and bond it to the underlying clay, thus serving as a desirable dust palliative. However, the parent clay may be too imperivous for such a liquid to penetrate sufficiently to be of service. In event the palliative possessed a hardening property upon drying, it might serve admirably to bond loose vegetative matter and prevent erosion about the fringe of the landing area where velocities of 50 to 100 mph occur.

c. Silty and Sandy Clays of the Temperate Zone. These surface soils are a medium bound cohesive material, slightly moist, moderately impervious, and support a sparse to vigorous vegetative growth depending on the season, that is, dry or wet. Untilled land areas normally have a thin surface mantle of fine sand or silt that erodes moderately under wind action. However, this mantle and the underlying parent soil may be successfully bonded by a chemical spray to resist aeolian erosion.

The foregoing highly plastic and moderately plastic soils and means of stabilizing them have been the subject of study since the advent of roadways and highways. Review has been made of 1372 literature references predating 1950, and 350 since, in order to seek out potential means of improving the stability and condition of natural surface soils for engineering uses. In general the stabilization processes developed have all involved manipulation of soil by either compaction or by admixing lime, cement, asphalt or other ingredients, and then compacting the combination. To effectively stabilize soil has required investigation in each instance involving sampling, testing and design or evaluation to arrive at a prescription. Numerous investigators have sought, used and reported on chemical or physico-chemical processes such as application of lignosol, phosphoric acid, chlorides and hydroxides of calcium and sodium, organic cationic chemicals, polyacids and lignin, fatty quaternary ammonium chlorides, lime, salt and many others.

The primary objectives of soil stabilization research and developments have been directed toward improvement of the stability of the untreated material by increasing the strength in shear and to preserve "built-in" states or conditions for hasty or short lived service. In this instance, the rapidly prepared landing sites are to be short lived. Minimum facilities and time are considered to be available for site preparation. Further, extreme

temperatures and erosive blast velocities are a part of the problem. These are factors that have not been involved in soil stabilization matters to date. However, based on our search, apparent solutions are indicated as treated in the paragraphs that follow.

a. Heat Effect. The heat conductivity of soil is very low, as treated previously. Therefore, except as the heat would affect surface vegetation and subsurface organic matter in the soil, serious consequences are not thought to be significant. Inquiry has developed the fact that grasses, weeds and similar small surface vegetation ignite in the temperature range of 400°F. Wood chips and fragments experience instantaneous combustion at 650°F. These substances must be anticipated to exist on the surface of untilled land. Therefore, landing surfaces must either be protected from exhaust engine blasts of 400°F range and greater or the vegetative matter be removed prior to use of a site to preclude undesired fires. For the exhaust blast area where temperatures in excess of 400°F occur, some form of ground cover must be provided. Two potential solutions appear worthy of consideration, as follows:

1. Combat Flame Throwers. Forward combat areas are in the control of combat troops which could be equipped with this combat tool. It may be used to burn off the surface vegetation quickly, prior to site use.

2. Combat Dozers. Combat Engineer Troops are normally available and equipped in forward areas with the standard heavy construction equipment, such as armored dozers. Accordingly, a dozer could strip the surface vegetation from a site in an estimated one hour, thus removing the fire hazard. This item of equipment can serve a dual purpose by tracking the area to mechanically stabilize the soil by compaction, the most commonly used stabilization process.

b. Erosion. The impinging exhaust blast, ranging in velocities from about 2000 mph to near zero, exceed the capacity of either natural or stabilized soils to retain their in-situ integrity. Current methods of soil stabilization are inappropriate for the rapidly prepared landing sites for proposed VTOL aircraft. This is due to the facilities, manipulation, control, and time required for their implementation.

CRITERIA FOR WHEEL BEARING

The design process used for non-rigid travel surfaces for military aircraft (Air Force and Army) is known as the California Bearing Ratio Method. It has been found through long use to be a very worthy and reliable method for both short lived and relatively permanent travel surfaces and pavements. Accordingly, it is considered appropriate for the short lived rapidly prepared landing areas for the VTOL aircraft under consideration.

Review of literature has disclosed a family of design curves correlating aircraft wheel loads, tire pressures and California Bearing Ratio (soil strengths) values for unsurfaces soil airfields, as developed by the U. S. Waterways Experiment Station, Vicksburg, Mississippi. The family of curves is for the minimum values of soil strength that will support aircraft wheel

loads for six coverages or stress repetitions on an identical spot. The family of curves has been reproduced and enclosed as Figure 2. The family of curves was developed for single wheels rather than duals such as are planned for the aircraft under consideration. It is noted that dual wheels are immediately adjacent to each other so that the tires, when bearing their load on a flat surface, would appear to deform and blend together, thus transferring the load as a single tire. Accordingly, the design curves are appropriate for the problem.

The leg or gear load for the typical aircraft was established as 18,000 pounds and tire pressures 35 psi. It may be noted from Figure 2 that the California Bearing Ratio required for support of a 20,000 lb. - 35 psi wheel is 3.75 for 6 coverages or repetitions. The term "coverages" may be unfamiliar and warrant brief explanation; in that, a coverage is a single application of a tire print over an area of interest. Landing of a VTOL type aircraft would be unusual if not difficult to settle on an identical spot more than once; therefore, six coverages could mean a life of numerous landings.

The minimum strength requirement of California Bearing Ration (CBR) of about 4 is considered to be a moderately low value. For untilled land areas that are moderately drained, one would expect such a value during normal weather. The value can be expected to be double or more during dry weather, whereas during protracted wet weather the value may decrease to the range of 2 or 3. At these lower values some rutting may be expected but adequate support should be expected.

It may be noted from the lower portion of the family of curves, Figure 2, that the required CBR values decrease with tire pressure. Accordingly, consideration may be given to reducing the tire pressure from 35 psi to some value such as 25 or 30 psi when operating on wet sites.

The U. S. Army Ground Forces have facilities for evaluating trafficability of terrain by the use of an instrument known as a "cone penetrometer." Combat Engineer Troops are provided with this equipment. Correlation of Calivornia Bearing Ratio Strengths with readings of the indicated instrument should be possible, so that it would be a simple matter to establish a "Cone Index Value" for the aircraft, such as exists presently for all army vehicles used in forward areas. This affords a ready field means for selecting a satisfactory site with minimum effort. Further, Army Ground Forces are now furnished Trafficability Terrain Maps for Combat Areas that would serve for preselecting sites for development. Thus rapid evaluation appears feasible by existing methods that are well established.

MEMBRANE THICKNESS

The thickness of the membrane used in rapid site preparation for VTOL aircraft becomes a factor of concern in two respects from the engineering point of view. The first factor relates to its strength properties when serving as a tension skin overlying unconsolidated soil which yields under aircraft loads. Anchorage of the membrane around the periphery of the site can result in significant supportability being mobilized, especially in cases of low strength natural soils. This ability can be exceedingly

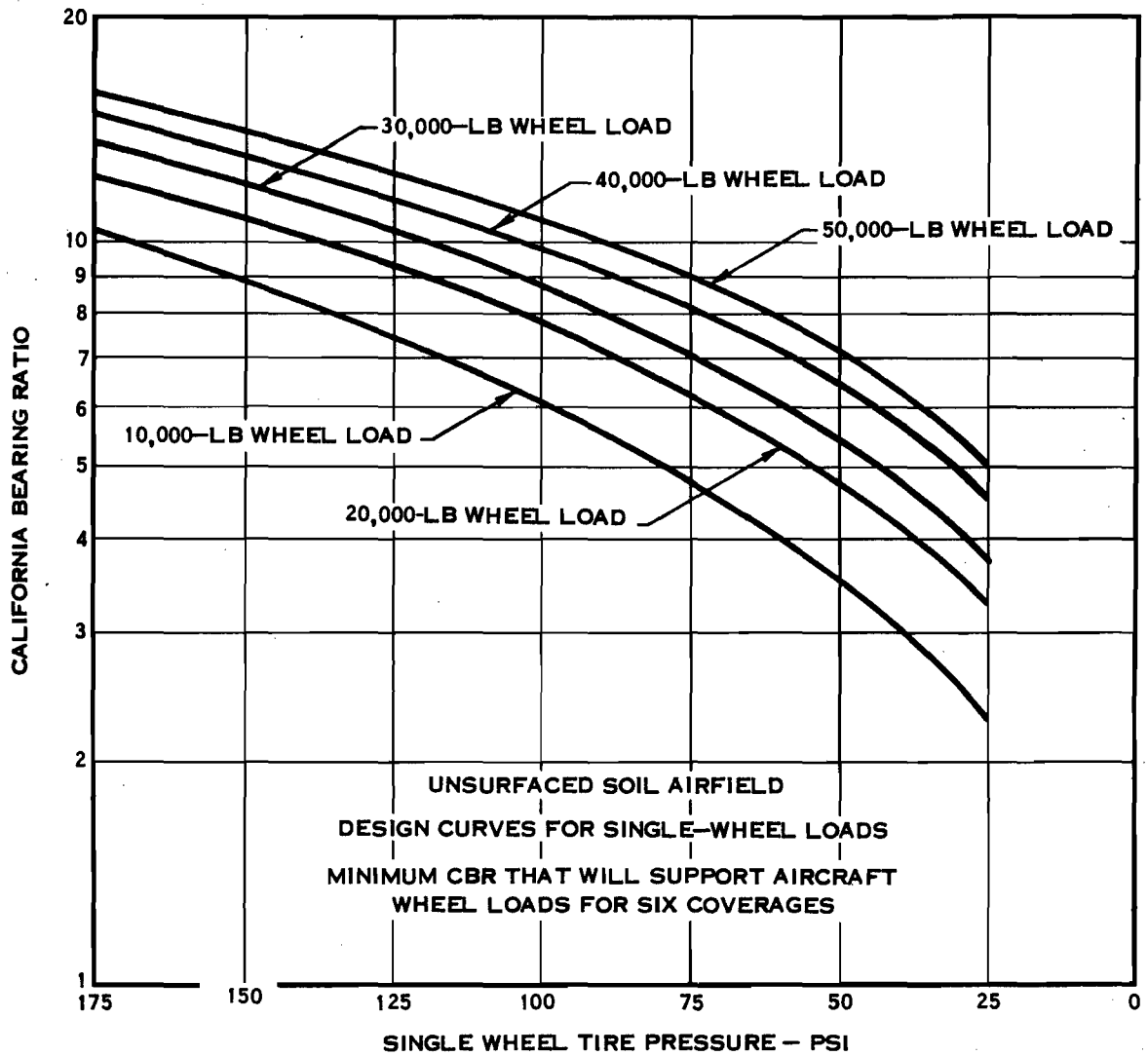


Figure 2 Single Wheel Tire Pressure vs California Bearing Ratio

beneficial for rapidly prepared sites, thus increasing the applicability of the process. It was indicated by results of the recent field experiment that peripheral anchorage is an important and desirable factor. It was found that on an off-center landing or take-off the exhaust blast serves to undermine the edge of the membrane, causing it to flutter and tear apart. Therefore, peripheral anchorage would serve a dual purpose. Consideration of the problem indicates several feasible solutions are available. The second factor relates to the elastic properties of the membrane, which in turn is related to its ability to deform, without rupturing, under the VTOL aircraft wheels on unprepared sites. It was stated earlier that rutting of the soil surface by wheels bearing 20,000 pounds could be anticipated. The elastic properties of the membrane material will strongly influence this capability. The recent successful field test with the experimental twin jet aircraft did not develop significant rutting. This was due largely to the relatively small wheel loads, estimated to be of the order of 2,000 pounds. It was understood the very dry soil subgrade was prepared by heavy discing prior to placement of the mat. In spite of this preparation little evidence of rutting appeared to have been experienced.

To achieve reasonable design of membrane thickness requires an appraisal of the strength and elastic properties of the material of which it is formed. The logistics requirement for forward area use warrants further careful consideration of this matter in order to balance both supportability and flexibility with the quantity of material required.

LABORATORY FACILITY FOR EVALUATION OF MEMBRANE THICKNESS

Evaluation of membrane thickness requirements for a global range of soils and anticipated conditions, on a realistic basis, dictates either a laboratory or field test facility. Consideration has been given to development of a feasible laboratory facility for this purpose. This facility would involve a container in which the representative soil types in nature-like conditions could be placed, the membrane fabricated over the top surface and the design wheel applied to the membrane under realistic loading. Preliminary analysis indicates a container 4.5 x 6 x 6 ft. will encompass the induced stress pattern for a contemplated aircraft tire. The California Bearing Ratio, Cone Penetrometer and other rapid means for field determinations of bearing capability can be used on the processed material. Thus the most feasible means for rapid field evaluation of this factor can be established and directly correlated with the reaction of the soils used in their different conditions, the behavior of the loaded wheels and the parameters for membrane deformation under rutting conditions can be established. Thus, the related factors could be established and evaluated under controlled conditions for both dynamic and static states, utilizing the elastic and strength properties determined under the preceding phase of study.

A field test facility may appear attractive at first thought; however, it is more difficult to manage than laboratory facilities. This results from difficulty in locating either natural soil deposits of the kind and condition desired, or the modification of the latter to conditions sought. Further,

the transportation of the membrane forming, loading and measuring apparatus from one location to another becomes a nuisance problem. Therefore, it appears that a laboratory facility would best serve the purpose.

DYNAMIC WHEEL LOADING

Landing of a VTOL aircraft causes the near instantaneous application of full wheel loads to the supporting medium under optimum circumstances. For less favorable circumstances, when near vertical drop of the aircraft occurs, significant impact must result. Once landed, the load is visualized to be a static case. This in turn would change to a rolling load when the aircraft is moved from one place to another on the prepared membrane. The near-instantaneous and impact loading circumstances are considered to be the most critical of the three mentioned, with the latter being of least importance.

Fundamental knowledge of the strength (shear) properties of soils subjected to impact of dynamic loading is limited at best. This is particularly true for surface soils normally occurring in a relatively low density or loose state. This is due, in turn, to such soils not having been subjected previously to significant overburden or other pressures, but rather to the action of transporting and weathering agents. The engineering profession rarely, if ever, uses soils in this condition, but rather manipulates them by compaction processes to develop their potential shear strength for economic reasons.

Review of knowledge of soils in "the surface loose state" shows that probably the best information has been that developed by the U. S. Army Waterways Experiment Station for their studies of trafficability. This knowledge is largely based upon experimental data correlated with field performance using land vehicles equipped with either standard and flotation type tires or crawler types of tracks. Individual loads for the single or multi-wheeled combinations are normally less than 10,000 pounds. This gives rise to the question of strict applicability for wheel loads which have double or more magnitude on VTOL aircraft. Further, the criteria for trafficability are based on rolling wheels with limited, if any, dynamic input to the supporting soil media.

Accordingly, two approaches develop for the solution of the problem of evaluating supporting capability of surface soils for VTOL aircraft wheel loads. The first approach is evaluation of representative surface soils by the method evolved for surface vehicles. Then try that system in the field with a rig simulating VTOL aircraft wheel and load application. The second approach is determination of the dynamic stresses induced in a surface soil mass, and comparison of such stresses with measured strengths of representative soils in conditions like they occur in nature at the ground surface. This second approach is the more rational of the two and, although recognized to be the more difficult, should be pursued. At the present level of knowledge, the soil mechanics engineer has the tools for measuring dynamic stresses induced in soil masses and is rapidly assembling the required knowledge of their uses, so answers are becoming a possibility.

It is concluded therefore that the most feasible approach to the solution of the problem is by first, thorough analysis of the technique and process used for land vehicles, and second, the rationalization of this knowledge for application to the problem of the greater wheel loads and dynamic manner loading representative of the VTOL aircraft.