AIR FORCE RESEARCH LABORATORY

MATERIALS AND MANUFACTURING

PARTICLE EROSION TEST APPARATUS

Use Policies, Operating Procedures & Specimen Configurations

Updated November 2018

University of Dayton Research Institute
300 College Park
Dayton, OH 45469-0054

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1.0 GENERAL INFORMATION

The AFRL Particle Erosion Test Facility is a government-owned facility operated by the University of Dayton Research Institute (UDRI) to serve the international aerospace community. Access is provided for both military and commercial testing. Priority of testing can usually be determined on a first-come, first-serve basis, but on occasion this order must be broken for more immediate or emergency evaluations. Failure to comply with the direction of erosion facility personnel can result in cancellation of testing. For more information about the AFRL/UDRI particle erosion test apparatus, contact:

Contractor Personnel **University of Dayton Research Institute**	**AFRL Government Personnel**
UDRI Erosion Facilities ATTN: Cheryl Castro 300 College Park Drive Dayton, OH 45460-0054 Office: (937) 255-2727 Particle Rig: (937) 904-5852 Cheryl.Castro.ctr@us.af.mil Cheryl.Castro.udri.udayton.edu	AFRL Particle Erosion Test Facility Coatings, Corrosion & Erosion Lab AFRL/RXSS (CCEL) ATTN: Joseph Shumaker 2179 12th St, Building 652 Rm 59 Wright-Patterson AFB, Ohio 45433-7718 (937) 255-2533 Joseph.Shumaker@us.af.mil

This brochure describes procedures for planning, scheduling, and performing testing in the Particle Erosion Test Apparatus of AFRL's Materials Durability and Sustainment Branch (AFRL/RXSS). The apparatus is located at Wright Patterson AFB and is operated by the University of Dayton's Research Institute (UDRI).

The apparatus was designed and built in the early 1980's for the Defense Nuclear Agency to simulate the effects of flight through a low concentration solid particle (dust) environment. Specific simulation requirements included particle sizes from 38 to 250 µm, particle mass fluxes as low as 1 mg/cm^2/min, particle velocities over a broad range of subsonic Mach numbers, and continuously adjustable impact angles from 20 to 90 degrees. Recent upgrades to the apparatus have included an updated laser Doppler anemometer (LDA) for particle velocity measurement, integration of the air pressure control valving and specimen and nozzle shaker controls into a single graphical user interface (GUI), and the addition of a boost pressure system to accelerate larger grains. The facility can accommodate historic sand loads and test speeds that have been used for many years on optical materials as well as the higher sand loads, grain sizes, and speeds used in testing for the rotorcraft community.

2.0 PARTICLE EROSION TEST APPARATUS

Particles are accelerated in a small diameter (approximately 0.25-inch) tungsten carbide high-speed gas jet and directed onto a test specimen as illustrated in **Figure 1**. Because the diameter of the jet is smaller than the test specimen area, the specimen holder and jet are articulated so that the test specimen is moved through the jet in a uniform manner. This articulation provides a uniform particle loading (particle mass intercepted per unit surface area) over a square area of approximately 316 cm^2 (i.e., 7 inches square). The inner 6-inch square is considered the valid test area. The specimen surfaces are located 4 inches from the nozzle exit when the nozzle is positioned level. Airfoil specimens will be positioned so their crowns are at 4 inches from the nozzle exit.

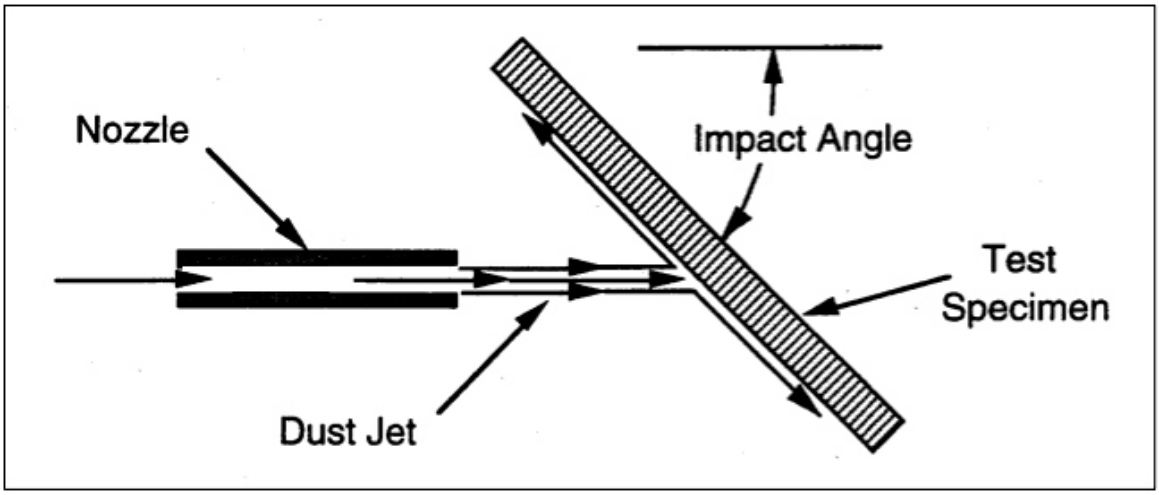

Figure 1: Particle Erosion Schematic

Compressed air provides the transport gas stream with regulators and pressure transducers to measure and control the pressure at the nozzle inlet. Particles are metered into the transport gas stream from a pressurized screw feeder system. The screw feeder provides a very accurate and uniform particle mass flow. The feed rates are established prior to each day of testing for foundry sand or between runs for large mass exposures using AFRL01 sand.

Velocity is determined by direct observation with the laser Doppler anemometer (LDA) prior to a day's testing. The pressure set point is controlled with a digital feedback loop during testing. The air pressure settings are rules of thumb for selected sand velocities and need to be confirmed on each day of testing. Slow test velocities may be influenced disproportionately by changes in ambient humidity and barometric pressure.

For a given test, a specific test velocity can be selected from this velocity versus pressure calibration. Particle size, velocity, and impact angle can be controlled independently. This

provides an excellent capability to parametrically evaluate the response of critical materials and coatings to solid particle impact effects. Materials from such components as rotorcraft blade coatings, leading edges, windscreens, radomes, paints, and any special coatings can be evaluated in a well-controlled laboratory environment under realistic but accelerated particle impact test velocities.

The Particle Erosion Test Facility differs from the real flight environment in that the specimen is stationary and the particle field is moving at the specified impact velocity. Whereas the key parameters in the flight environment are the static cloud mass concentration (mass or volume of particles per unit volume) and velocity, in the particle erosion facility the key parameters are the particle mass loading and velocity. The relationship between the mass loading in the test facility, and dust cloud concentration, impact velocity, and time in the flight environment is as follows:

Mass Load = Concentration * speed * time (* unit conversion factors).

Example: a facility publishes ~1 x 10^{-6} m^3 / m^3 as their concentration. A typical test is 279 MPH for 10 minutes. Some conversions before writing the final equation:

$$1\times10^{-6}\ m^3/_{m^3}\times 4227\ cup/_{m^3}\times 383\ g/_{cup}=1.619\ g/_{m^3}$$

279 MPH = 125 m/s
10 min. = 600 seconds
Cup = quart/4 (just like in the kitchen)

Directly calculating the equivalent mass load:

Mass Load = Concentration * speed * time * unit conversion

$$12.1425\ g/_{cm^2}=1.619\ g/_{m^3}\times 125\ m/_{s}\times 600s\times 1\times10^{-4}\ m^2/_{cm^2}.$$

Similarly, with this concentration at 500 MPH (224 m/s) for 30 seconds, the mass load is 1.088 g/cm^2. At a high setting of 337 grams in a 4 minute pass covering 310 cm^2, the UDRI test produces a mass load of 337 g/310 cm^2 or 1.087 g/cm^2, equal to 30 seconds in this very dense concentration at the desired speed of 500 MPH.

3.0 USE POLICIES

3.1 Erosion and Failure Analysis

Materials evaluated for particle erosion resistance are normally either bulk type or coated. Damage is evidenced by erosion loss or coating adhesion failure. Such terms as pitting, cratering, cracking,

material loss or fracture, core-crushing, and delamination are used to describe the progressive performance of the materials.

In addition, the following quantitative metrics are available to evaluate materials:

- Mass Loss
- Optical Microscopy and Image Analysis
- Haze and Luminous Transmittance (ASTM D1003) for transparent materials
- IR Spectroscopy for transmission analysis of infrared window materials
- Chemical craze testing

Also, materials are often subjected to rain erosion testing before or after particle testing. Prospective users are encouraged to discuss appropriate erosion evaluation tests with UDRI or AFRL prior to scheduling of tests.

3.2 Specimen Geometries

There is some flexibility in specimen geometry, as the only motion is the translation across the particle stream. For short duration tests, specimens have been mounted with adhesive tape. It is preferred, however, to use existing fixtures to ensure reliable and repeatable results. Fixtures are on hand for 1 inch square, 1.5 inch square, 1 inch round, airfoil, and several other rectangular configurations. Additional configurations can be made available if needed but will entail additional costs. Please contact facility personnel to discuss requirements.

3.3 Test Conditions

A test condition consists of five independently variable parameters that define the exposure environment during the test. These parameters are:

1. **Particle Type** - The type of sand used for the specific test is determined by the needs of the customer. Foundry and AFRL01 sands are nominally 100% quartz sands. Both are naturally sourced and so may include some impurities that do not have a noticeable influence on test results. Typical optical materials are tested with Foundry sand. This erosion media is very round and is what was historically used to perform all optical materials testing in this facility prior to 2010. Tough materials do not erode in a manner like that found during normal use. The Foundry sand may be capable of aiding in evaluating the relative erosion resistance of tough materials. The damage caused by Foundry sand on tough materials is not like that found on surfaces exposed to sandy desert environments. The use of Foundry sand on tough materials will produce anomalously low erosion rates for a given mass exposure. AFRL01 sand has been developed as a testing media in this facility for producing damage comparable with that

found on surfaces serving at or near the ground in desert environments. Great success has been had in evaluating the erosion resistance of very tough materials at an accelerated rate. This is the material required for testing helicopter rotor blade protective surfaces according to MIL-STD-3033, *Particle/Sand Erosion Testing of Rotor Blade Protective Materials.*

2. **Size** – Foundry and AFRL01 sands are sieved in-house into a limited number of particle sizes. AFRL01 sand is typically available as a 240 to 550 µm diameter erosion media. Grains larger than 550 µm diameter do not flow uniformly through the sand delivery nozzle and there is no AFRL01 sand recovered in usable quantities that is smaller than 240 µm diameter. Standard Foundry sands are available in the following size ranges (µm): 38-44, 44-53, 53-74, 74-88, 88-105, 105-125, 125-149, 149-177, 177-250. Particle sizes are distributed within each of these ranges. Combinations of these ranges may also be used to create a custom range and particle distribution. Other media may be used, contact UDRI or AFRL for availability.
3. **Velocity** – Particle stream velocity for Foundry sand can be specified at any value in the range of 100 to about 650 MPH. The velocity of AFRL01 sand is a maximum at 500 MPH. Velocity is determined by placing the laser crossover of the LDA at the center of the particle stream at a position 4 inches in front of the nozzle exit. A typical velocity profile is presented in **Figure 2**.
4. **Impact Angle** – Impact angle can be specified at any value in the range 90° (normal incidence) to 20°, as measured from a line laying within the plane of the sample (**Figure 1**.) Brittle specimens are typically tested at normal incidence. Tough organics and most metals will be tested at some angle between 30 and 60 degrees from normal.
5. **Mass Loading** – The mass of impinging particles, given in g/cm^2 of sample area, can be specified to almost any value. Small mass loading results in short exposure duration, while larger mass loading simply requires a longer exposure time. Typical values of mass loading vary widely and are in the range 0.001 g/cm^2 (extremely light) to greater than 50 g/cm^2 (extremely heavy). **MIL-STD-3033** recommends a mass exposure of 25 g/cm^2 for testing very erosion resistant helicopter rotor blade coatings.

NOTE: For specific test condition, mass loading may be specified in increments, with evaluations (mass loss, IR transmission, etc.) conducted between each increment. Be aware that the number of sample removals, weight determinations, etc, will dramatically extend the length of time needed to do testing. All specimens will be weighed in the lab before and after testing if mass loss testing

is performed. The customer may elect to use or ignore the measurements taken but the measurements will be recorded.

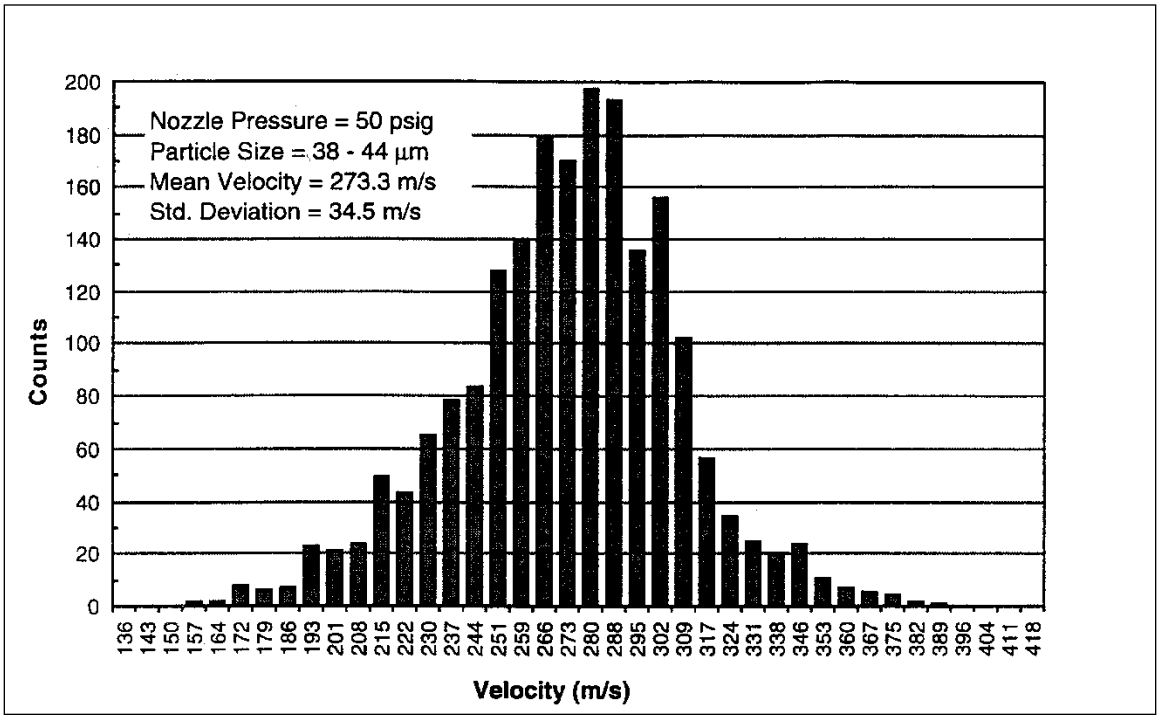

Figure 2: Typical Velocity Profile.

3.4 Scheduling

3.4.1 Test Scheduling

Due to the frequent, high demand usage of the erosion facility, prospective users are urged to schedule test dates well in advance. Scheduling is normally accomplished by calling UDRI at Wright-Patterson Air Force Base; Office: (937) 255-2527, Particle Rig: (937) 904-5828, or FAX (937) 255-0954.

Address US Postal correspondence to:

UDRI Erosion Facilities
ATTN: Cheryl Castro
300 College Park
Dayton, OH 45460-0054
Office: (937) 255-2527
Particle Rig: (937) 904-5828

Cheryl.Castro.ctr@us.af.mil
Cheryl.Castro@udri.udayton.edu

Note: Do not use this address to ship samples. See Section 3.9 for sample shipment requirements.

IMPORTANT!! SPECIAL ARRANGEMENTS MUST BE MADE FOR DOD CLASSIFIED TEST SPECIMENS. NOTIFY EROSION FACILITY PERONNEL WHEN SCHEDULING TEST DATES IF SPECIMENS ARE CLASSIFIED.

3.4.2 Payment Scheduling

Payment arrangements are substantially different for users with a U.S. Government sponsor and those without a sponsor. To avoid delays or cancellation of testing, it is recommended that payment scheduling be arranged as soon as possible after test scheduling.

3.4.2.1 Users with a U.S. Government Sponsor

Users with a sponsor must contact the Financial Division of the Air Force Research Laboratory (AFRL/RXFM) at (937) 255-9765 to arrange payment conditions as soon as possible after scheduling test dates. This is often a time-consuming process, but payment conditions must be

arranged before testing can take place. **Testing will be delayed or cancelled if payment conditions are not arranged.**

3.4.2.2 Users Without a U.S. Government Sponsor

Users without a U.S. Government sponsor operate on a purchase order basis with the University of Dayton Research Institute (UDRI). The user company must submit the signed "Test Description and Approval Form" (Appendix A) enclosed in the Formal Proposal from the UDRI office of Contracts and Grants; [937-229-2919] In addition to the signatures of the UDRI collaborator and an official from the user company, the form will lastly be signed by AFRL/RXS for completion.

The purpose of this form is to provide mutual assurance of safety, responsibility, and confidentiality of testing and test results. Suitable time must be allowed to obtain the signatures on this form, especially with the users' company. **Any discussion or questions regarding this form should be raised as soon as possible after test scheduling. Testing may be delayed or cancelled if payment conditions are not arranged at least two weeks prior to the test date(s).**

3.5 Cancellation Policy

Users who cancel or postpone a scheduled test must contact UDRI **at least two weeks prior to the scheduled test date(s).** Users who fail to make timely notification will be charged 20% of the scheduled test cost. Exceptions to this charge will be made in the event of inclement weather, personal emergency, or in the event that UDRI can schedule another user in the testing dates that had been reserved for the original user. In the event that UDRI must cancel testing because payment conditions have not been arranged or necessary documents have not been received, the same cancellation policy will apply.

3.6 Test Plan

Users must submit a test plan to guide and direct their specific test needs. Before scheduling testing, the users should know the number of specimens, geometry, classification (DOD classified or unclassified), mass load(s), media size, and if any intermediate measurements or inspections are required. Prospective users are encouraged to discuss their test plans thoroughly with erosion facility personnel well before the scheduled test date. In addition to technical matters, guidance can often be provided regarding the necessary paperwork.

The test plan must include an adequate specimen material description, required velocity and angular modes, order of testing, and mass load(s).

The test plan must be submitted to erosion facility personnel to allow sufficient time for review and clarification, normally several days prior to the scheduled test date. The test plan serves as a basis for the evaluation sheet used by the erosion facility operator at the time of testing. If the test plan is late or not submitted, the testing may be delayed or cancelled.

3.7 Specimen Description

It has long been the policy of AFRL (Air Force Research Laboratory) to maintain a complete database of all particle erosion test results from the erosion facility. This data constitutes the history and progress of particle erosion resistant material development and is accessed only under a strict USAF need basis. Specimens to be tested must be accompanied by a description sufficient to allow the inclusion of the material and the results into the database. This description can be generic, but it must include at least the class of material(s) being evaluated, with some indication as to material treatment, coating thickness, etc.

EXAMPLE:

Polyurethane topcoat, light gray, 0.006" thickness / Polyurethane rain erosion coating, dark gray, 0.020" thickness / Epoxy primer, light green, 0.004" thickness / Chromate-free pretreatment / Aluminum Airfoil

3.8 Specimen Evaluation/Retention

Many times, a further post-test analysis of the specimens can add significantly to the test data. For a complete test performance analysis, a post-test analysis is conducted. To complete this evaluation, it is necessary for the testing personnel to retain the specimens for one or two days after testing. This will allow the specimens to be given an experienced second look under magnification and without the pressures of continuing facility operation. Without this post-test analysis UDRI cannot guarantee the complete performance evaluation of test materials.

3.9 Specimen Shipment

This document describes the many sizes and shapes of specimens that can be tested at the erosion facility. Specimens must conform to one of these configurations. It is strongly recommended that specimens be shipped **no less** than 7 days in advance of the scheduled test date to allow for dimensional checking. If there is any concern about specimen configurations please contact erosion facility personnel (Section 1.0 General Information).

Ship specimens via Fed Ex or UPS to:

UDRI Erosion Facilities
ATTN: Cheryl Castro
AFRL/RXSS (CCEL), Erosion Facilities
2700 D Street, Building 1661, Room C110
Wright-Patterson AFB, OH 45433

IMPORTANT: The address above cannot be used for shipment of classified materials.

IMPORTANT: If test specimens are hand-carried to the erosion facility on the day of testing and do not fit the testing assembly, the test time will be abbreviated or canceled.

3.10 Data Submission

Following the test and evaluation sequence, an electronic copy (PDF) of the detailed test report is emailed to the user; a hard copy of the report is available upon request. All test results and all test specimens are handled on a strict proprietary basis. No endorsement of materials is intended either by the USAF or UDRI.

3.11 On-Site Visitors

Users are welcome to witness the testing of their specimens. Due to facility and safety restrictions, up to three visitors per test are allowed. Prior notification is required and the visitors must contact contractor or government personnel listed in Section 1.0 General Information to gain access to Wright-Patterson Air Force Base.

4.0 SPECIMEN DIMENSIONS

4.1 Square Specimens

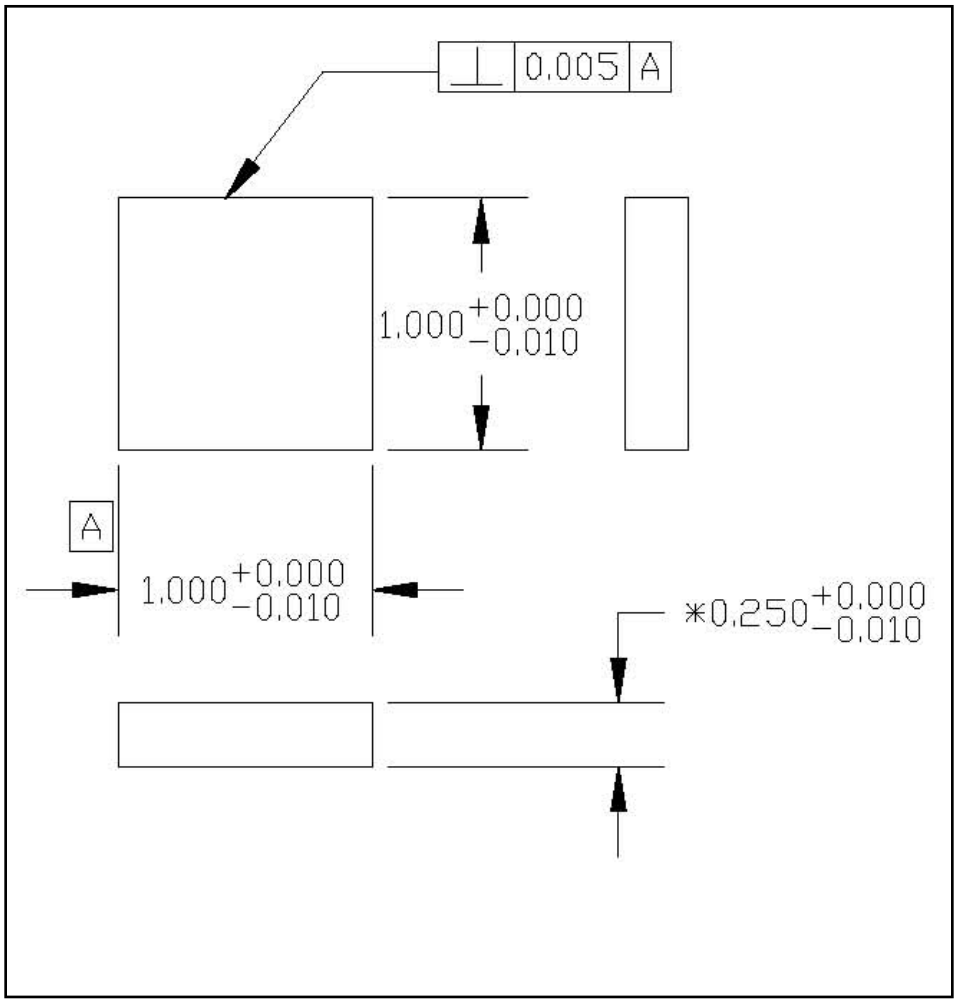

Figure 3: Square Specimen – Configuration 1

- All dimensions in inches
- Total dimensions include coating thickness if any
- * Specimens can be any thickness from 0.125 to a maximum of 0.250.
- For specimen thicknesses under 0.250, shims may be added under specimens for a total mounting thickness of 0.250.

Note: IR transmitting materials should be a minimum of 0.200.

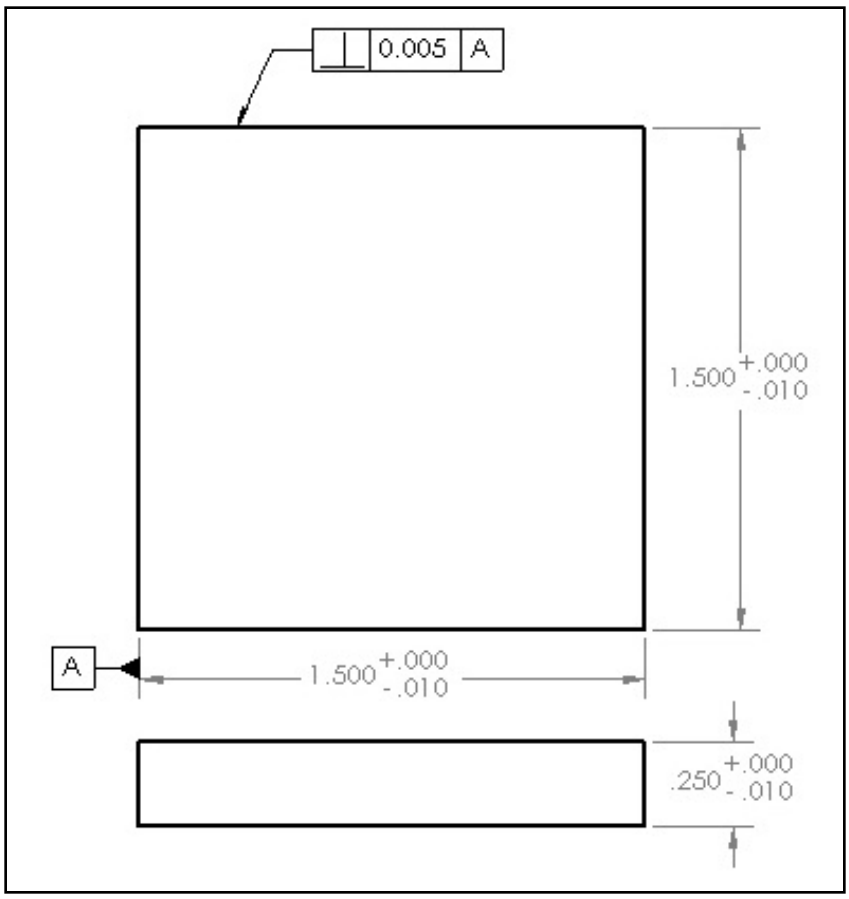

Figure 4: Square Specimen – Configuration 2

- All dimensions in inches
- Total dimensions include coating thickness if any
- Specimens can be any thickness from 0.125 to a maximum of 0.250.
- For specimen thicknesses under 0.250, shims may be added under specimens for a total mounting thickness of 0.250.

Note: IR transmitting materials should be a minimum of 0.200.

4.2 Round Specimen

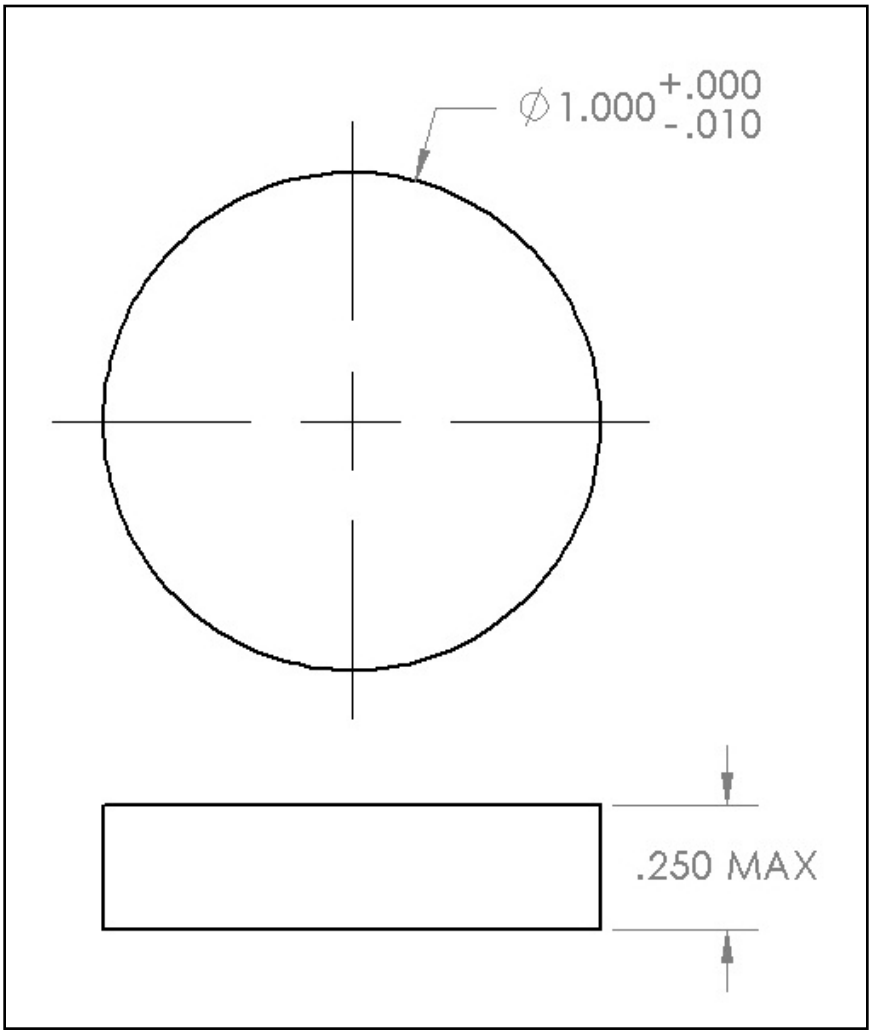

Figure 5: Round Specimen – Configuration 1

- All dimensions in inches
- Total dimensions include coating thickness if any
- Specimens can be any thickness from 0.125 to a maximum of 0.250
- For specimen thicknesses under 0.250, shims may be added under specimens for a total mounting thickness of 0.250.

Note: IR transmitting materials should be a minimum of 0.200

4.3 Rectangular Specimens

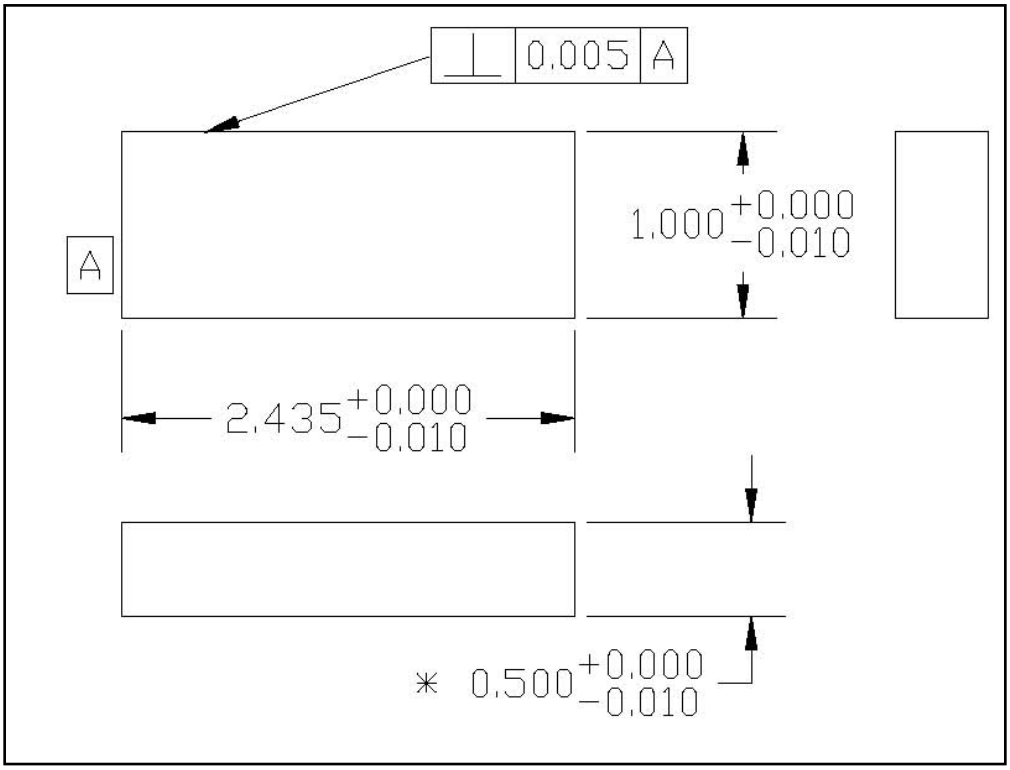

Figure 6: Rectangular Specimen – Configuration 1

- All dimensions in inches
- Total dimensions include coating thickness if any
- Specimens can be any thickness from 0.125 to a maximum of 0.500.
- For specimen thicknesses under 0.500, shims may be added under specimens for a total mounting thickness of 0.500.
- Maximum weight of specimen is 190 grams.

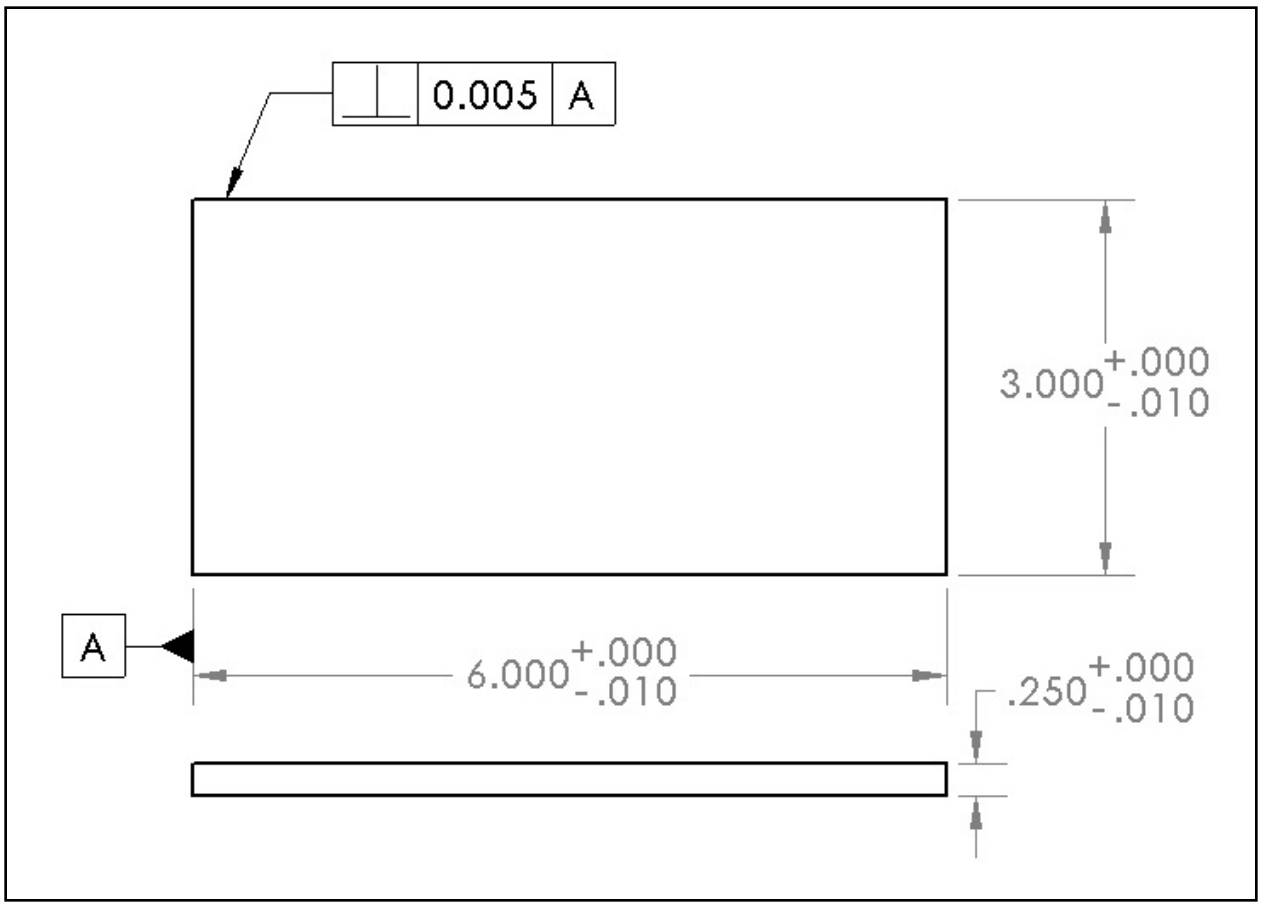

Figure 7: Rectangular Specimen – Configuration 2

- All dimensions in inches
- Total dimensions include coating thickness if any
- Specimens can be any thickness from 0.125 to a maximum of 0.250.
- For specimen thicknesses under 0.250, shims may be added under specimens for a total mounting thickness of 0.250.
- Maximum weight of specimen is 190 grams.

4.4 Leading Edge Airfoil Specimens

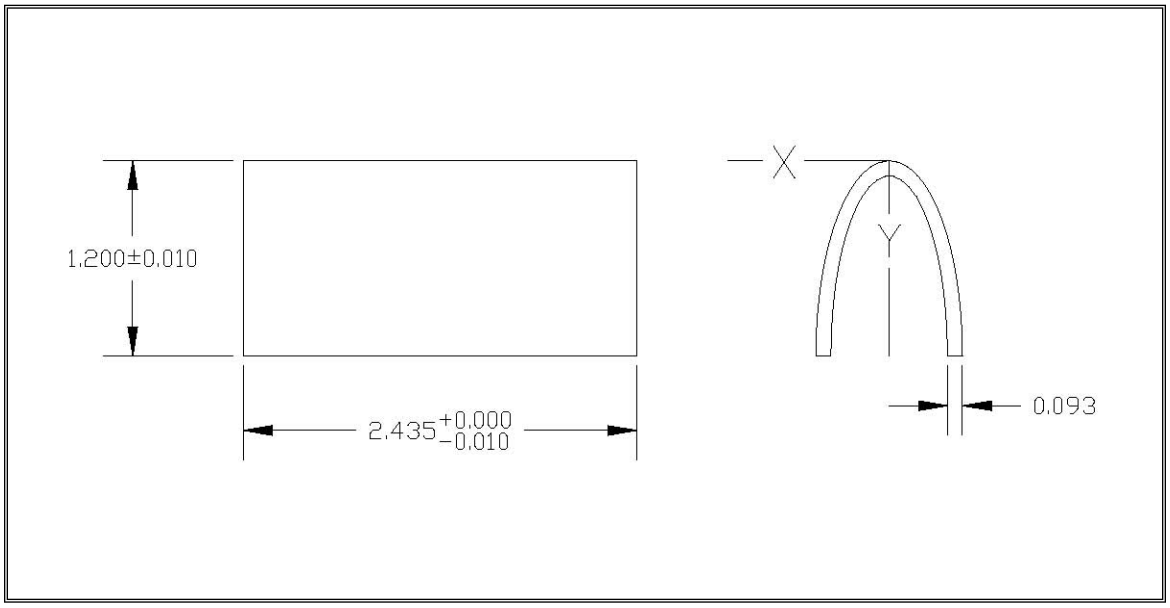

Figure 8: Composite Leading Edge Airfoil Specimens – Configuration 1

% Chord	(Y) Ordinate	(X) Abscissa
.00	.00	.000
1.25	.05	.112
2.50	.10	.172
5.00	.20	.250
7.50	.30	.304
10.00	.40	.344
15.00	.60	.400
20.00	.80	.432
25.00	1.00	.439
30.00	1.20	.454

- All dimensions in inches

NOTE: Coatings applied to this airfoil configuration average 0.010 – 0.020 inches in thickness with a maximum thickness limited to 0.050 inches.

Maximum weight of the specimen is 200 grams.

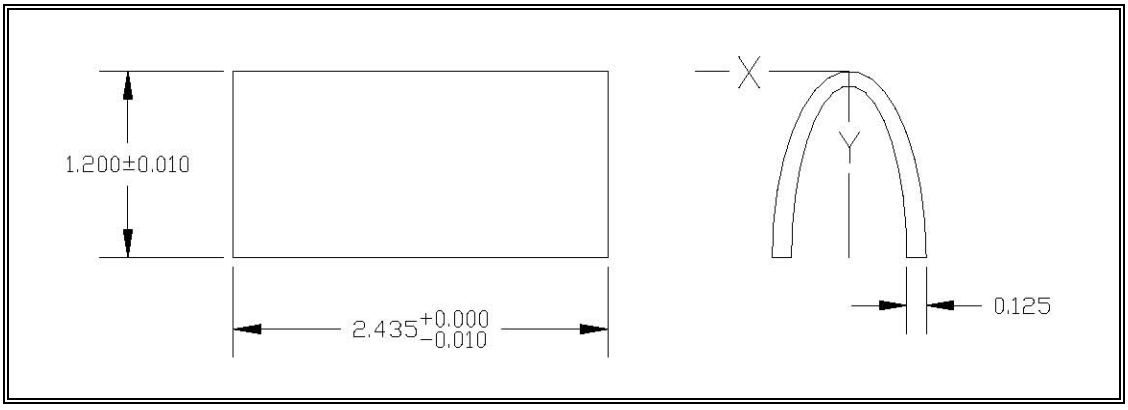

Figure 9: Metallic Leading Edge Airfoil Specimens – Configuration 1

% Chord	(Y) Ordinate	(X) Abscissa
.00	.00	.000
1.25	.05	.158
2.50	.10	.218
5.00	.20	.296
7.50	.30	.350
10.00	.40	.390
15.00	.60	.446
20.00	.80	.478
25.00	1.00	.485
30.00	1.20	.500

- All dimensions in inches

NOTE: Coatings applied to this airfoil configuration average 0.010 – 0.015 inches in thickness with a maximum thickness limited to 0.040 inches.

Maximum weight of the specimen is 200 grams.