

METHODS FOR DETERMINING TURBINE NOZZLE AREA

1. **INTRODUCTION:** This report addresses methods for measuring the area of gas turbine nozzles. Nozzle area is a critical element of engine performance and it must be precisely controlled during manufacture and subsequent rework. Several techniques will be discussed in obtaining the dimensions required for the formula solution of Simpsons Area Rule by mechanical means. This produces the Geometric Flow Area (GFA) as opposed to waterflow (ARP 1067A) or air flow (ARP 1195) which result in Effective Flow Area (EFA).
2. **PURPOSE AND SCOPE:** The intent of this report is to provide descriptions of some commonly accepted practices in measurement technology. It will also touch upon advanced experimental systems employing more sophisticated equipment.
3. **MEASUREMENT LOCATIONS AND FORMULAE:** The number of measurement points, their location within the nozzle opening, and the mathematical weight applied to each must be analytically determined and empirically confirmed by correlation tests with engine performance runs and/or other accepted methods of nozzle measurement. The total area of the nozzle is equal to the sum of the individual throat openings.

Simpsons Rule for Area Measurement is depicted in Figure 1. It relates only to mechanical methods for determining GFA. The mathematical weighting shown generally will apply only to new nozzle partitions. Experience may dictate changing weighting values as partitions distort with age or cycle through rework. This formula is the basis for computation in automated and semi-automated instruments. Since this report is oriented primarily to GFA measurements, flow techniques (EFA) will be treated only briefly in discussion.

CANCELLED

July 1993

SAE Technical Board rules provide that: "All technical reports, including standards approved and practices recommended, are advisory only. Their use by anyone engaged in industry or trade or their use by governmental agencies is entirely voluntary. There is no agreement to adhere to any SAE standard or recommended practice, and no commitment to conform to or be guided by any technical report. In formulating and approving technical reports, the Board and its Committees will not investigate or consider patents which may apply to the subject matter. Prospective users of the report are responsible for protecting themselves against liability for infringement of patents."

SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your written comments and suggestions.

4. GENERAL CONSIDERATIONS: GFA as measured by the gages described herein will more closely correlate with engine performance runs or EFA when:
- o The nozzle design and manufacturing process produces a repeatable contour, such as results from a casting vs. a fabrication.
 - o The nozzle is relatively large, such that minor variations in contour and seal leakage have a small percentage effect on EFA.
 - o The trailing edge is relatively straight.
 - o The concave side of the airfoil at the line of intersection with the trailing edge is free of cooling holes or other discontinuities.
 - o The amount and type of allowable rework is consistent along the entire length of the trailing edge.
 - o Surface finish is consistent on new, used, and reworked nozzles.

The measuring equipment and the item to be measured should be temperature stabilized prior to beginning of the measurement process. Hand-held units may exhibit measurement variations due to thermal conduction after several minutes of use, and should be re-set to the master as required.

5. DISCUSSION: Throughout the industry, there are many variations in nozzle design, and each presents area measuring problems peculiar to a particular engine line. Rework and repair introduce more anomalies. Typical nozzle designs are:
- a. 360° welded/brazed fabrication.
 - b. Assembly of individual cast partitions.
 - c. Assembly of segments containing two or more partitions.
 - d. One piece cast ring.

Any of the above may be structured with internal air cooling passages. Should the cooling air re-enter the gas path through trailing edge slots, accuracy of measurement can be further compromised. Rework, a term normally associated with engine overhaul, can be performed on new nozzles that fall out of area limits. Depending on material available and type as well as cooling configuration, partitions can be deflected at the trailing edge to effect closure or ground to increase flow path area. Following each rework action, remeasurement is required to confirm result, thus the operation must be accurate, repeatable and fairly rapid.

5. DISCUSSION (Continued):

Precision measurement is essential to process control both during manufacture and repair at overhaul. Fabricated nozzles in particular are subject to jig/fixture induced error and creep during subsequent heat treatment. Repairs can add material during brazing and reduce effective area. Stripping a diffusion bonded coating can result in removal of the parent material, thus producing an increase in gas flow. Also presenting a measurement problem is allowable trailing edge bow, wherein a partition is distorted within serviceable limits. Assemblies of cast segments raise the question of accuracy due to the variable gap between segments. While they are constrained during measurement, they may not actually maintain the relationship under gas loads at elevated temperature.

From the above discussion, it can be realized that precision repeatable area measurement, a major factor in engine performance, provides a real challenge to those designing the equipment as well as to operators who perform the task. There follows a resume of the primary methods of area measurement, a discussion of their features, capabilities and limitations.

6. DETAILED METHODS:

6.1 Waterflow (Ref: ARP 1067A):

Considered to be the most accurate system until the late 1960s, this method measures in thousandths of seconds the time for an exact volume of water to pass through an assembled nozzle. The system is expensive and the towers take an excessive amount of shop space. Sealing and leakage are major problems with segmented nozzles. As more sophisticated systems became available, waterflow correlation, thus accuracy was seriously challenged. From these studies, "window effect" was identified, (a downstream wake turbulence that caused flow inconsistencies). This was particularly true of nozzle designs in which the partitions do not overlap when viewed parallel to the engine axis, thus "windows" are apparent. Wake turbulence is a variable present to some degree in all nozzles, and not necessarily repeatable between identical assemblies. As a rule, water flow specifications call for an average of five flow timings, which adds substantially to the time to measure. Waterflow is affected by variations in temperature and the water must be stilled after tank fill. The flow path must be extremely smooth to prevent vortex induced errors.

6.2 Air Flow (Ref: ARP 1195):

This system is essentially a measurement of the differential in back pressure from controlled air flow through the test piece in parallel with a series of masters, or a variable orifice adjusted to match the back pressure of the test article. The former requires three master comparisons, one to be within 10% of nominal, and two at 50% and 150% of this figure. Normally, pressurized air is used, however suction systems offer the advantage of avoiding temperature variables induced by compression and expansion. ASME spec masters are preferred to engine hardware to assure more precise control.