SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4961

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Weights, Tube Fitting, Estimating, Weighing and Maintaining, Procedure for

RATIONALE

ARP4961 has been reaffirmed to comply with the SAE five-year review policy.

TABLE OF CONTENTS

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TABLE OF CONTENTS (Continued)

1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) establishes procedures for estimating the weight of parts, weighing actual parts at time of manufacture and maintaining and collecting the weight data.

1.1 Purpose:

This document establishes the basic rules to estimate the weights of the parts by determining the volume from geometry of the part(s) with consistent degree of accuracy; to obtain the actual weight of the parts; and to store, transfer, and update the information pertinent to the weights.

2. REFERENCES:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 ASM International Publications:

Available from ASM International, Metals Park, OH 44073.

ASM Metals Handbook, 9th Edition

2.2 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-45662 Calibration Systems Requirements

3. PROCEDURE FOR ANALYTICAL CALCULATIONS:

3.1 General Rules:

This section describes basic rules to use when estimating the volume of the part and provides some densities of common materials to be used in calculating the weights.

3.1.1 The portions of the part shall be calculated separately (see 3.2). For each portion of the fitting, the outside shaped solid volume shall be calculated first; the volume of the removed (at the inner diameter(s)) material shall be calculated separately and then subtracted from the outside volume. The summation of these component volumes is the basic volume of the part. A 10% allowance for maximum material condition shall be added to the basic volume value to obtain the final estimated volume value.

3.1.2 The calculations shall be performed using nominal values of the dimensions. The diameter of the threaded section(s) is considered to be the pitch diameter of the thread. The diameters are calculated as such; the radii larger than .120 in are considered as radii in the calculations. The .062 to .120 in radii shall be approximated by two straight line segments (see Figure 1). Full radii, .031 to .062 in shall be considered 45° chamfers, the line being tangent to the radius at a 45° angle. The radii and chamfers less than .031 in are not to be considered in the calculations.

3.1.3 The final volume value shall be multiplied by the density of the fitting material. The density values for common aerospace materials are given in Table 1. For different materials, the conversion factor from one to the other may be calculated using these values.

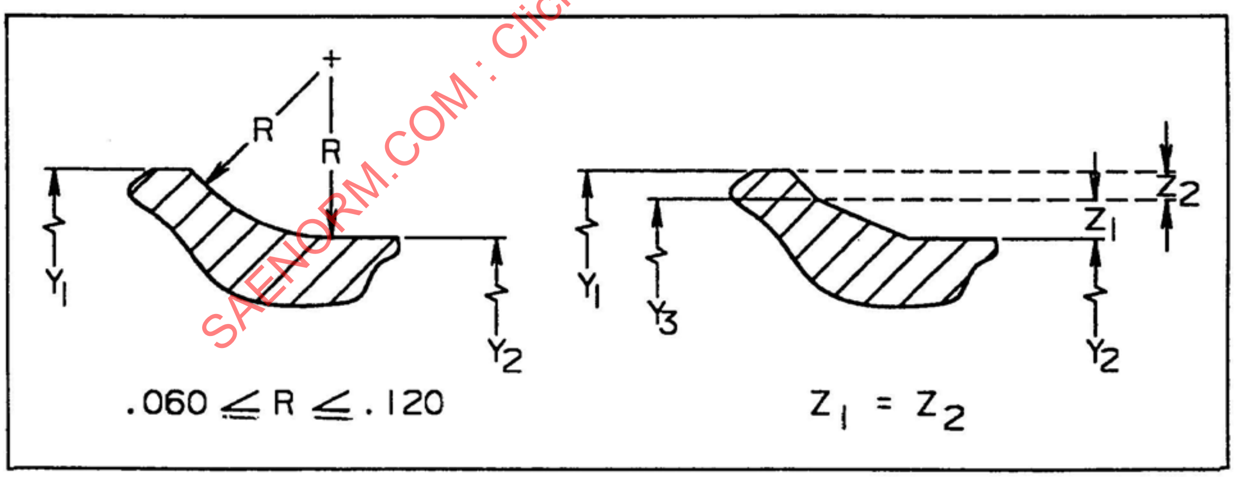

FIGURE 1 - Approximation of Radius

TABLE 1 - Density of Common Aerospace Materials[1)]

Material	Density, lb/in^3
Aluminum alloy 2014	.101
Aluminum alloy 2024	.100
Aluminum alloy 7075	.101
Copper base alloy, brass alloy 360	.307
Corrosion resistant steel, type 304, 316, 321, 347	.29
Corrosion resistant steel, type 17-5PH, 15-5PH	.28
Inconel 718	.296
Titanium alloy, 6Al4V	.160
Low carbon steel, 1008, 1024	.284

1) From ASM Metals Handbook, 9th Edition except Inconel 718 from supplier catalog.

3.1.4 Initial calculations shall utilize four significant figures; the final estimate value of the part volume shall be rounded off to three significant figures.

3.2 Section Volume Estimate:

This section provides the detailed rules to calculate the actual volume of the part from the geometry in order to estimate the weight.

3.2.1 Fitting End Volume: The fitting end volume shall be defined by each fitting end configuration; the geometry shall be divided into cylindrical or conical sections, as applicable, and the width of each section shall be restricted by the diameter or by a combiation of diameters for a conical section configuration. An example is given in Appendix A.

3.2.2 Center Block Section Volume: The center block section shall be defined for elbows, tees, and crosses and unions as illustrated in Appendix B through F. The formulae are as follows:

$$\text{Tee center volume} = .8927V^3 - 1.178A^2V + .3927A^3 \quad \text{(Eq. 1)}$$

$$90^\circ \text{ Elbow center volume} = .7736V^3 - .7854A^2V \quad \text{(Eq. 2)}$$

$$45^\circ \text{ Elbow center volume} = .3253 \times (V^3 - A^2V) \quad \text{(Eq. 3)}$$

$$\text{Cross center volume} = V^3 - 1.571A^2V + .7854A^3 \quad \text{(Eq. 4)}$$

$$\text{Union/straight adapter center hex volume} = .8660H^2W - .7854A^2W \quad \text{(Eq. 5)}$$

where:

A = inside hole diameter
H = hex size
V = across wrench pad dimension and leg diameter
W = width of hex

3.2.3 Volume of Portion Between Center Block Section and Fitting End of Shape Fittings: The portion between the center block section and the fitting end is usually cylinder-shaped. The guidelines to calculate the volume are given in Appendix G.

3.2.4 Sleeve Transitional Area Volume Estimate: The transitional area which connects the sections of sleeve ends is usually cylinder-shaped. The guidelines to calculate this volume are given in Appendix H.

3.2.5 Retained Nut and Tube Nut Volume Estimates: The configuration is different for each particular part and it is advised to calculate them separately for each particular case. The geometry usually consists of hexagonal and cylindrically shaped portions. An example to calculate the volume is given in Appendix J.

3.3 Computer Three Dimensional CAD (Computer Assisted Design) Volume and/or Weight Estimates:

The technique to obtain the volume and/or the weight of the part shall be determined by the user of the particular computer software, in which case the compliance with 3.1 through 3.2.5 is optional except Table 1 shall be used. The degree of accuracy may vary due to the limitations of computer capabilities.

3.4 Data Storage and Control:

The following suggestions are to avoid duplicating the same calculations, to prevent the usage of obsolete data and to maintain and use the data.

3.4.1 The volume values for the most frequently encountered fitting ends may be calculated once, stored, and reused for future weight estimates. It is advised to record the revision level of the standard from which the volume has been calculated. In case the fitting end is dimensionally changed, the difference in volume should be added or subtracted. When the fitting end is modified for special applications, the difference in volume shall be taken into account when the basic volume of the part is computed.

3.4.2 The volume value for the standard center body section may also be reused provided that the difference made by the material removed or not removed at inner diameters will be taken into account when the basic volume of the part is computed.

3.4.3 The volumes of portions between the center body section and the fitting end or the transitional area of the sleeves will vary for each part configuration; it is advised to recalculate these component volumes for each particular fitting. It is also advised to calculate the hex portion volume for straight adapters/unions for each configuration individually.

3.4.4 The estimated weights may be included on the part standards provided that the drawing states so. The estimated values shall not be used after actual weight has been obtained.

3.4.5 The list of the estimated final weights shall be maintained and the source (analytical calculations, computer program, or unknown) shall be noted. The list will be updated as more data becomes available; at the time of the revision, it shall be checked if the actual weight of the part has been determined, compared to the estimated, and noted so in the document.

4. PROCEDURE FOR OBTAINING ACTUAL WEIGHTS BY WEIGHING:

4.1 Procedure:

The following procedure is intended to ensure the accuracy and consistency of actual weight data as well as to maintain a periodically updated list of the actual weights.

4.1.1 The parts shall be weighed using well maintained equipment calibrated per MIL-STD-45662. Fittings or their assembly components shall be weighed before packaging. Assemblies, special modified parts, and semifinished parts shall not be weighed. A random sample of the parts in a manufacturing lot will be selected to be weighed as a weight lot. The total weight will then be divided by the number of parts in the weight lot to obtain an average weight of the part in the lot. The minimum amount of pieces in the lot should be as follows:

a. 5 pieces for tube size 16 and larger
b. 10 pieces for tube size 08 through 14
c. 20 pieces for tube size 06 and smaller

If there are fewer pieces than the minimum, weigh them all. More pieces than the minimum may be weighed if desired.

4.2 Data Accumulation:

Two separate documents shall be maintained:

a. One for continuous accumulation of weighing data (see 4.2.1)
b. Another for finalized data (see 4.2.2)

4.2.1 The continuous record of weights should include the following information:

a. Amount of pieces in each weight lot
b. Weight of the lot
c. Average calculated weight of one part
d. Drawing revision level

The weight shall be recorded to four significant figures in pound-mass for standard parts and grams for metric parts. When necessary, the conversion factor of 453.6 g/lb will be used. The continuous weight record will be reviewed for three separate lot values within 5% of each other. See 4.2.2.

4.2.2 The weight of the part shall be the average of three values, obtained from different weight lots and not more than 5% different from each other. If the difference is due to bar stock versus forging configuration, it should be noted and parts separated into different weight lots and noted so in the records. This final weight values shall be rounded off to three significant figures. For assemblies, the weight of the components shall be added together. The separate weight document shall be maintained to record the final weight data. The copy of weight documents shall be available for Subcommittee G-3B and others.

5. NOTES:

5.1 Dimensions:

Dimensions in inches.

5.2 Key Words:

Weights, estimating, tube fitting

APPENDIX A
EXAMPLE OF FITTING END VOLUME CALCULATIONS

A.1 FITTING ENDS:

Equation A1 may be used to calculate the volume of the fitting end as shown in Figure A1.

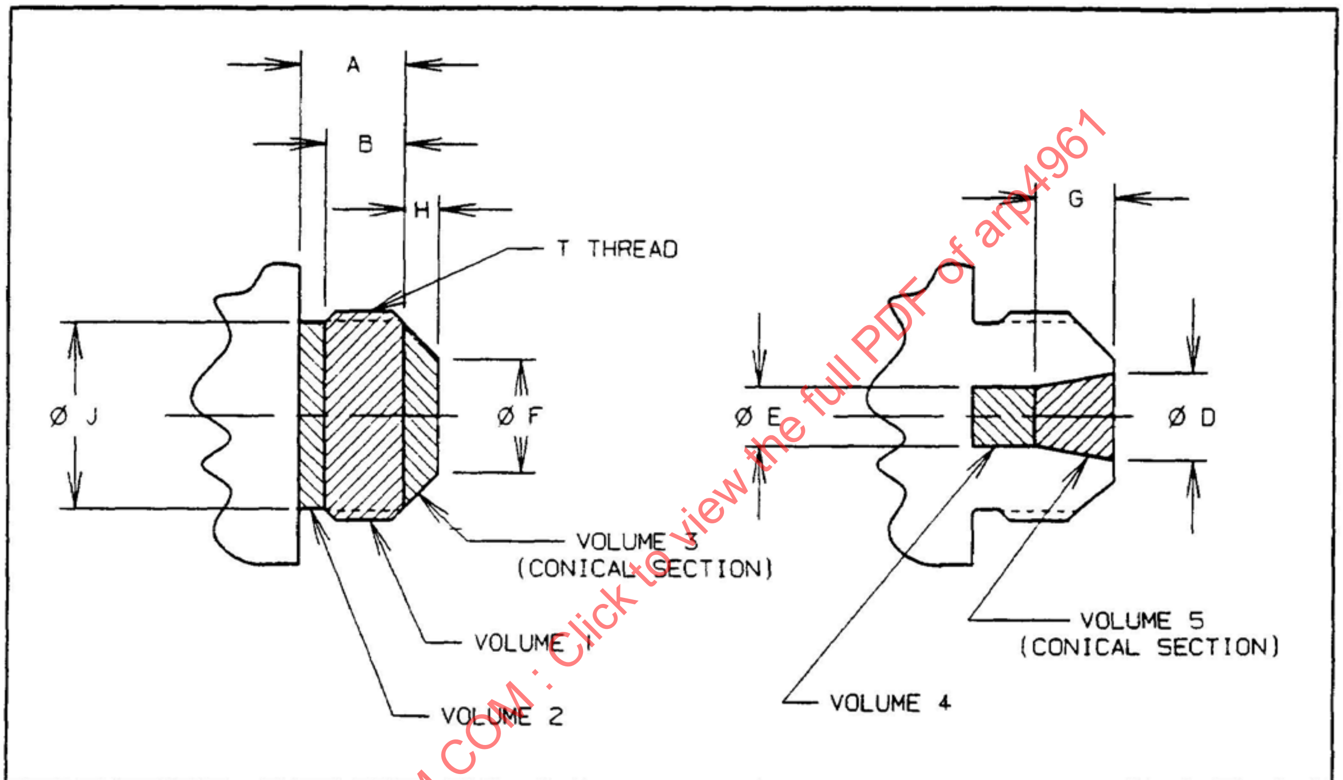

FIGURE A1 - Example of Fitting Ends

$$\begin{aligned}
\text{Volume } 1 &= \pi / 4 \times (\phi\text{T pitch})^2 \times \text{B} \\
\text{Volume } 2 &= \pi / 4 \times (\phi\text{J})^2 \times (\text{A} - \text{B}) \\
\text{Volume } 3 &= \pi / 12 \times [(\phi\text{T pitch})^2 + (\phi\text{T pitch}) \times (\phi\text{F}) + (\phi\text{F})^2] \times \text{H} \\
\text{Volume } 4 &= \pi / 4 \times (\phi\text{E})^2 \times (\text{A} + \text{H} - \text{G}) \\
\text{Volume } 5 &= \pi / 12 \times [(\phi\text{D})^2 + (\phi\text{D}) \times (\phi\text{E}) + (\phi\text{E})^2] \times \text{G} \\
\text{Total Volume} &= \text{Volume } 1 + \text{Volume } 2 + \text{Volume } 3 - \text{Volume } 4 - \text{Volume } 5
\end{aligned} \qquad \text{(Eq. A1)}$$

APPENDIX B
DERIVATION OF FORMULA OF TEE CENTER BLOCK SECTION VOLUME

B.1 TEE CENTER BLOCK:

Equation B1 may be used to obtain the volume of a tee center block section as shown in Figures B1 and B2.

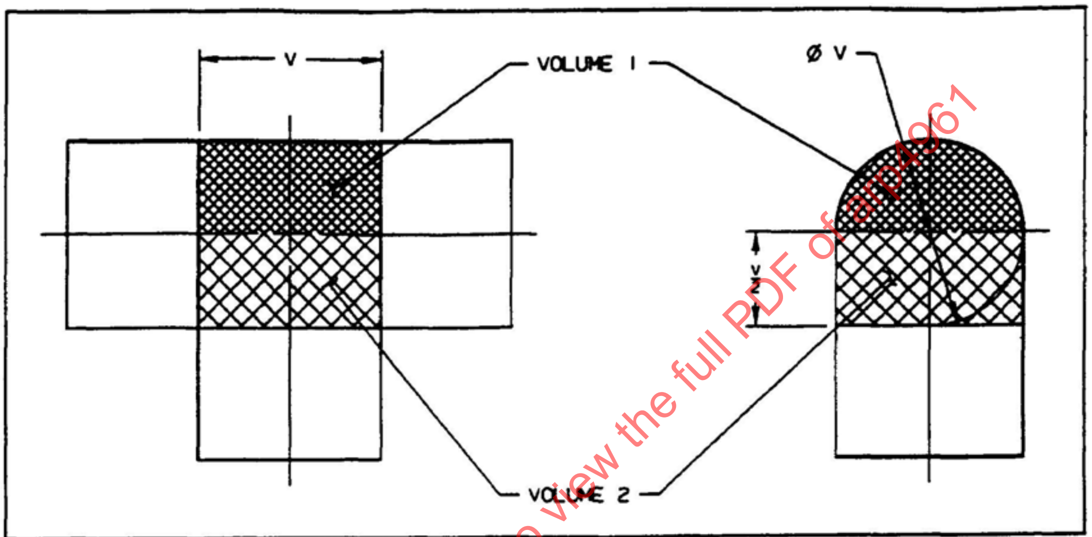

FIGURE B1 - Tee, Center Block Section Volume, Outside Shaped Volume

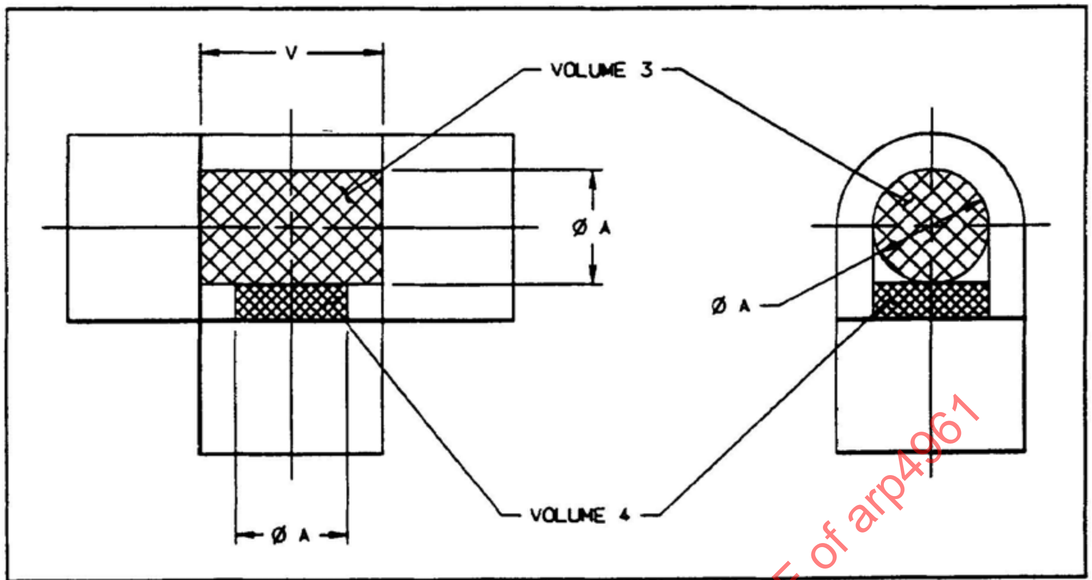

FIGURE B2 - Tee, Center Block Section Volume, Inner Volume

B.1 (Continued):

$$\text{Volume } 1 = V \times (\pi / 4) \times V^2 \times (1/2) = (\pi / 8) \times V^3$$
$$\text{Volume } 2 = V \times V\,(V/2) = (1/2)\,V^3$$
$$\text{Volume } 3 = V \times (\pi / 4) \times A^2 = (\pi / 4) \times A^2 V$$
$$\text{Volume } 4 = (\pi / 4) \times A^2 \times (V/2 - A/2) - (\pi / 8) \times A^2 V - (\pi / 8) \times A^3 \qquad \text{(Eq. B1)}$$
$$\text{Center Block Section Volume} = \text{Volume } 1 + \text{Volume } 2 - \text{Volume } 3 - \text{Volume } 4 =$$
$$V^3 \times (\pi / 8) \times V^3 - (\pi / 4) \times A^2 V - (\pi / 8) \times A^2 V + (\pi / 8) \times A^3 =$$
$$(\pi / 8 + 1/2) \times V^3 - (3\pi / 8) \times A^2 V + (\pi / 8) \times A^3 =$$
$$.8927V^3 - 1.178A^2V + .3927A^3$$

APPENDIX C
DERIVATION OF FORMULA OF 90° ELBOW CENTER BLOCK SECTION VOLUME

C.1 ELBOW CENTER BLOCK SECTION:

Equation C.1 may be used to obtain the volume of a 90° elbow center block section as indicated by Figures C1 and C2.

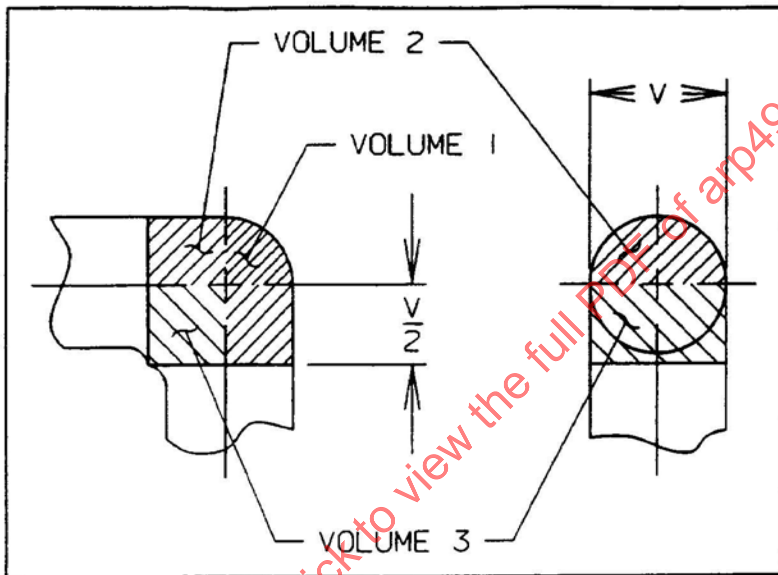

FIGURE C1 - 90° Elbow, Center Block Section Volume, Outside Shaped Volume

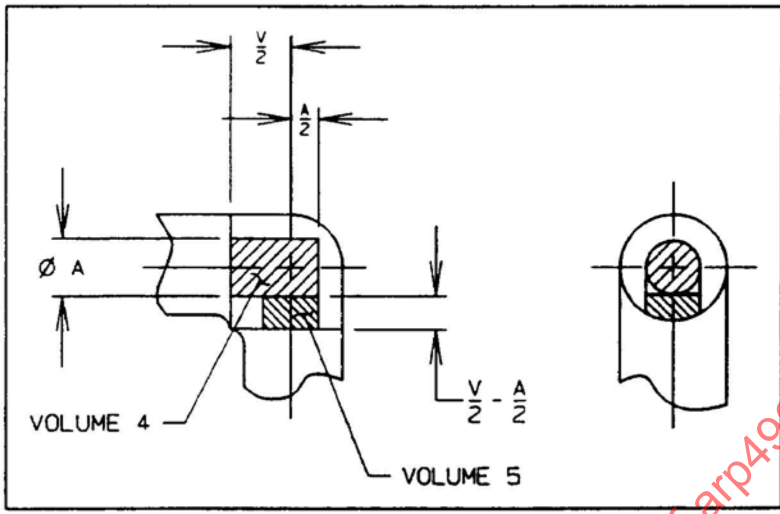

FIGURE C2 - 90° Elbow, Center Block Section Volume, Inner Volume

C.1 (Continued):

$$
\begin{aligned}
&\text{Volume } 1 = (1/4) \text{ x } (\pi/6) \text{ x } V^3 = (\pi/24) \text{ x } V^3 \\
&\text{Volume } 2 = (1/2) \text{ x } (\pi/4) \text{ x } V^2 = (\pi/16) \text{ x } V^3 \\
&\text{Volume } 3 = (V/2) \text{ x } (V/2) \text{ x } V = (1/4)\, V^3 \\
&\text{Volume } 4 = (\pi/4) \text{ x } A^2 \text{ x } (V/2 + A/2) = (\pi/8) \text{ x } A^2V + (\pi/8) \text{ x } A^3 \\
&\text{Volume } 5 = (\pi/4) \text{ x } A^2 \text{ x } (V/2 - A/2) = (\pi/8) \text{ x } A^2V - (\pi/8) \text{ x } A^3 \\
&\text{Center Block Section Volume} = \text{Volume } 1 + 2 \text{ x } (\text{Volume } 2) + \text{Volume } 3 - \text{Volume } 4 - \text{Volume } 5 = \\
&(\pi/24) \text{ x } V^3 + 2 \text{ x } (\pi/16) \text{ x } V^3 + (1/4) \text{ x } V^3 - (\pi/8) \text{ x } A^2 \text{ x } V \\
&- (\pi/8) \text{ x } A^3 - (\pi/8) \text{ x } A^2V + (\pi/8) \text{ x } A^3 = \\
&(\pi/24) + (\pi/8) + (1/4) \times V^3 - (\pi/4) \times A^2V = \\
&.7736V^3 - .7854A^2V
\end{aligned}
\qquad \text{(Eq. C1)}
$$

APPENDIX D
DERIVATION OF FORMULA OF 45° ELBOW CENTER BLOCK SECTION VOLUME

D.1 ELBOW CENTER BLOCK SECTION:

Equation D1 may be used to obtain the volume of 45° elbow center block section as indicated by Figures D1 and D2.

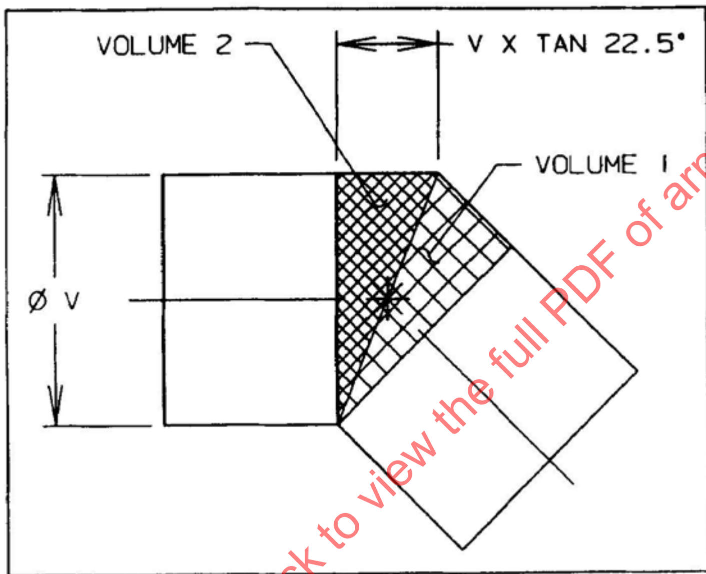

FIGURE D1 - 45° Elbow, Center Block Section Volume, Outside Shaped Volume

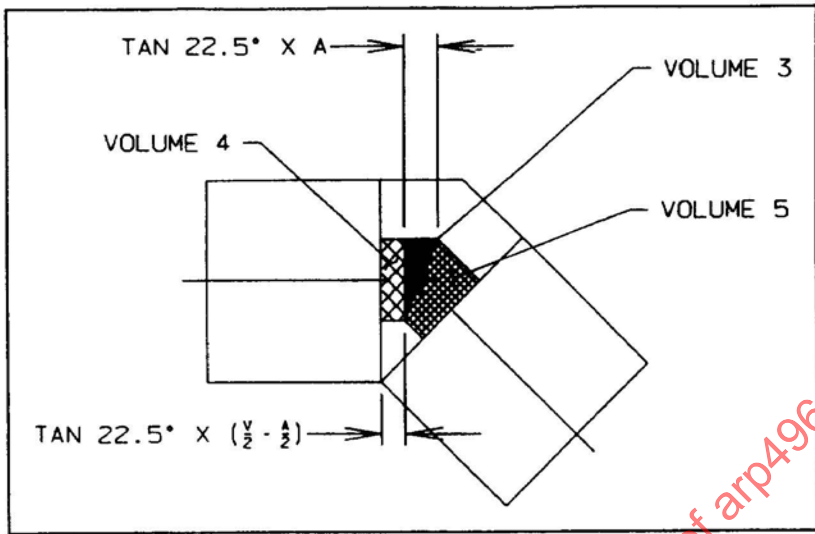

FIGURE D2 - 45° Elbow, Center Block Section Volume, Inner Volume

D.1 (Continued):

$$\text{Volume 1} = \text{Volume 2} = (1/2) \times (\pi / 4) \times V^2 \times V \times \tan 22.5^\circ = (\pi / 8) \times V^3 \times \tan 22.5^\circ$$

$$\text{Volume 3} = (\pi / 4) \times A^2 \times \tan 22.5^\circ \times A \times (1/2) = (\pi / 8) \times \tan 22.5^\circ \times A^3$$

$$\text{Volume 4} = (\pi / 4) \times A^2 \times \tan 22.5^\circ \times (V/2 - A/2) = (\pi / 8) \times A^2 \times \tan 22.5^\circ \times (V - A)$$

$$\text{Volume 5} = \text{Volume 3} + \text{Volume 4}$$

$$\text{Center Block Section Volume} = 2 \times (\text{Volume 1} - \text{Volume 5}) = \qquad \text{(Eq. D1)}$$

$$2 \times (\pi / 8) \times \tan 22.5^\circ \times V^3 - 2 \times (\pi / 8) \times \tan 22.5^\circ \times A^3 -$$

$$2 \times (\pi / 8) \times A^2 \times \tan 22.5^\circ \times V + 2 \times (\pi / 8) \times \tan 22.5^\circ \times A^3 =$$

$$(\pi / 4) \times \tan 22.5^\circ\ V^3 - (\pi / 4) \times \tan 22.5^\circ \times A^2 \times V =$$

$$.3253\ (V^3 - A^2V)$$

APPENDIX E
DERIVATION OF FORMULA OF CROSS CENTER BLOCK SECTION VOLUME

E.1 CROSS, CENTER BLOCK SECTION VOLUME:

Equation E1 may be used to obtain the volume of a cross center block section as indicated by Figure E1.

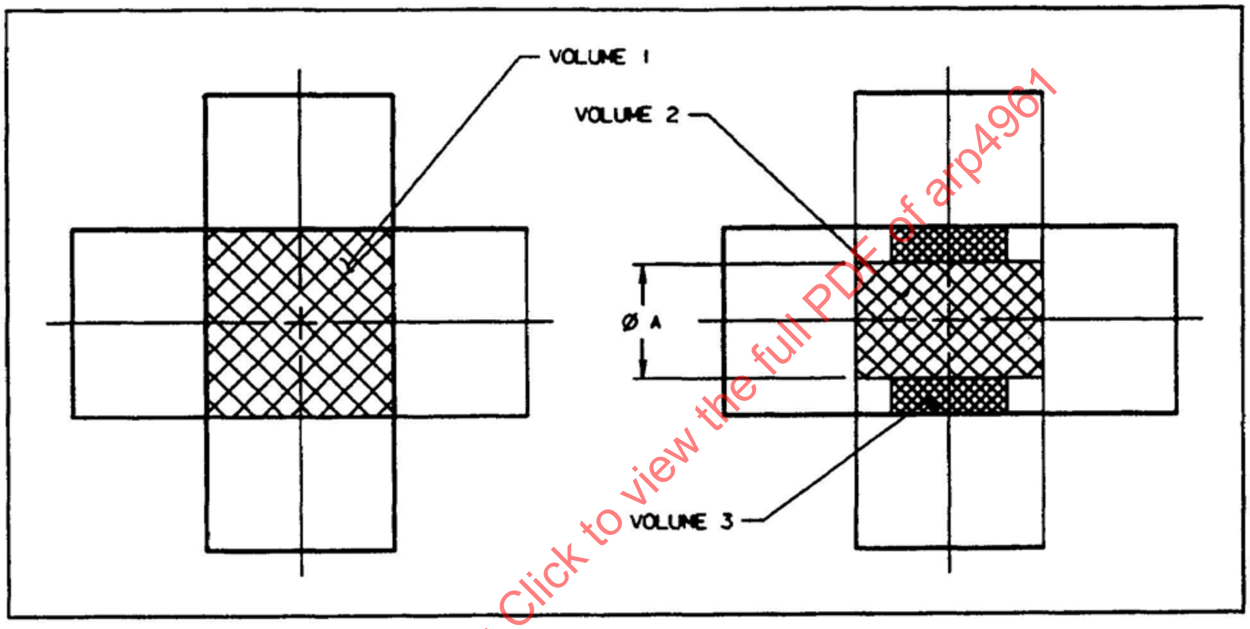

FIGURE E1 - Cross, Center Block Section Volume

$$\text{Volume } 1 = V^3$$
$$\text{Volume } 2 = (\pi / 4) \times A^2 \times V$$
$$\text{Volume } 3 = (\pi / 4) \times A^2 \times (V / 2 - A / 2)$$
$$\text{Center Block Section Volume} = \text{Volume } 1 - \text{Volume } 2 - 2 \text{ x } (\text{Volume } 3) = \qquad \text{(Eq. E1)}$$
$$V^3 - (\pi / 4) \text{ x } A^2 \text{ x } V - (\pi / 4) \text{ x } A^2 \text{ x } V + (\pi / 4) \text{ x } A^3 =$$
$$V^3 - (\pi / 2) \text{ x } A^2 \text{ x } V + (\pi / 4) \text{ x } A^3 =$$
$$V^3 - 1.571A^2V + .7854A^3$$

APPENDIX F
DERIVATION OF FORMULA OF UNION/STRAIGHT ADAPTER CENTER HEX VOLUME

F.1 UNION/STRAIGHT ADAPTER, CENTER HEX VOLUME:

Equation F1 may be used to obtain the center hex volume as indicated by Figure F1.

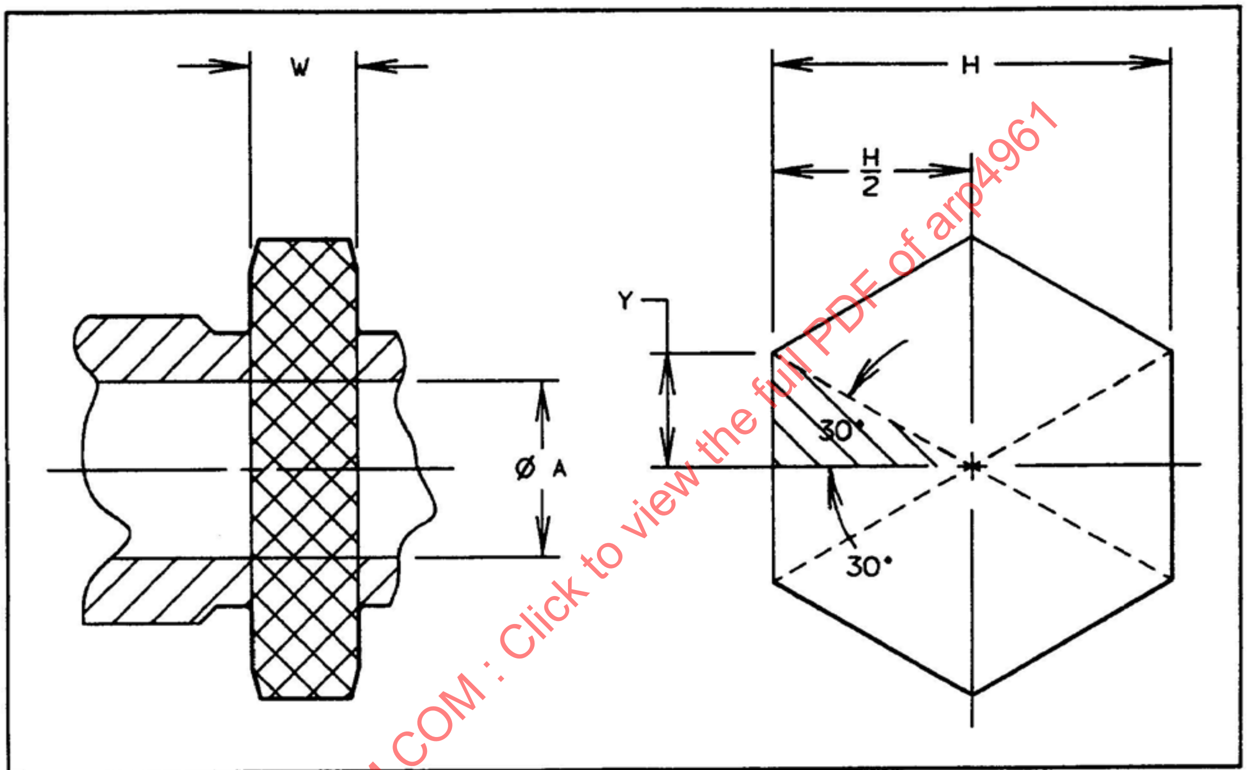

FIGURE F1 - Union/Straight Adapter, Center Hex Volume

$Y = (H / 2) \times \tan 30°$

Hex area $= (1 / 2) \times (H / 2) \times Y \times 12 = (1 / 2) \times (H / 2) \times (H / 2) \times \tan 30° \times 12 = (3 / 2) \times \tan 30° \times H^2$

Hex Volume $= (3 / 2) \times \tan 30° \times H^2 \times W$

Inner Dia Volume $= (\pi / 4) \times (\phi A)^2 \times W = (\pi / 4) \times A^2 \times W$ (Eq. F1)

Union / Straight Adapter, Center Hex Volume = Hex Volume − Inner Dia Volume =

$(3 / 2) \times \tan 30° \times H^2 \times W - (\pi / 4) \times A^2 \times W =$

$.8660\ H^2W - .7854\ A^2W$