



AEROSPACE INFORMATION REPORT

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Superseding AIR6082

Calculations to Determine Dimensions for Backup Rings
to AS5781, AS5782, AS5860, AS5861

RATIONALE

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FOREWORD

Scarf cut backup rings to AS5781 and AS5860 are dimensioned to accommodate cylinder breathing and thermal shrink at low temperature while maintaining a 50% minimum lap at the scarf cut. They are also designed, where possible, to ensure an axial clearance between the O-Ring, backup ring(s) and groove at high temperature with an overlap condition at the scarf cut. These calculations under thermal conditions do not account for thermal changes to any of the hardware.

Solid uncut backup rings to AS5782 and AS5861 are dimensioned in line with practical tolerances on diameters.

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1. SCOPE

This AIR documents the methodologies used to calculate the dimensions and tolerances used in the following backup rings standards:

- AS5781
- AS5782
- AS5860
- AS5861

In addition, an appendix is provided which provides details of gland and backup ring design practices.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. 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.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AS568	Aerospace Size Standard for O-Rings
AS4716	Gland Design, O-Ring, Packings and Other Elastomeric Seals
AS5781	Retainers (Backup Rings), Hydraulic and Pneumatic, Polytetrafluoroethylene Resin, Single Turn, Scarf-Cut, For Use in AS4716 Glands
AS5782	Retainers (Backup Rings), Hydraulic and Pneumatic, Polytetrafluoroethylene Resin, Solid, Un-Cut, For Use in AS4716 Glands
AS5857	Gland Design, O-Ring and Other Elastomeric Seals, Static Applications
AS5860	Retainers (Backup Rings), Hydraulic and Pneumatic, Polytetrafluoroethylene Resin, Single Turn, Scarf-Cut, Static Gland
AS5861	Retainers (Back-Up Rings), Hydraulic and Pneumatic, Polytetrafluoroethylene Resin, Solid, Static Gland
AS8791	Hydraulic and Pneumatic Retainers (Back-Up Rings), Polytetrafluoroethylene (PTFE) Resin
AMS3678	Polytetrafluoroethylene (PTFE) Moldings and Extrusions, Unfilled, Pigmented and Filled Compounds

2.1.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <https://assist.daps.dla.mil/quicksearch>

MIL-G-5514 Gland Design; Packing, Hydraulic, General Requirements For (Inactive for New Design)

FED-STD-595 Colors Used in Government Procurement

2.2 DEFINITIONS

GLAND DESIGN DIMENSIONS: The key hardware dimensions for glands, as defined in AS4716 and AS5857, are as shown in Figure 1.

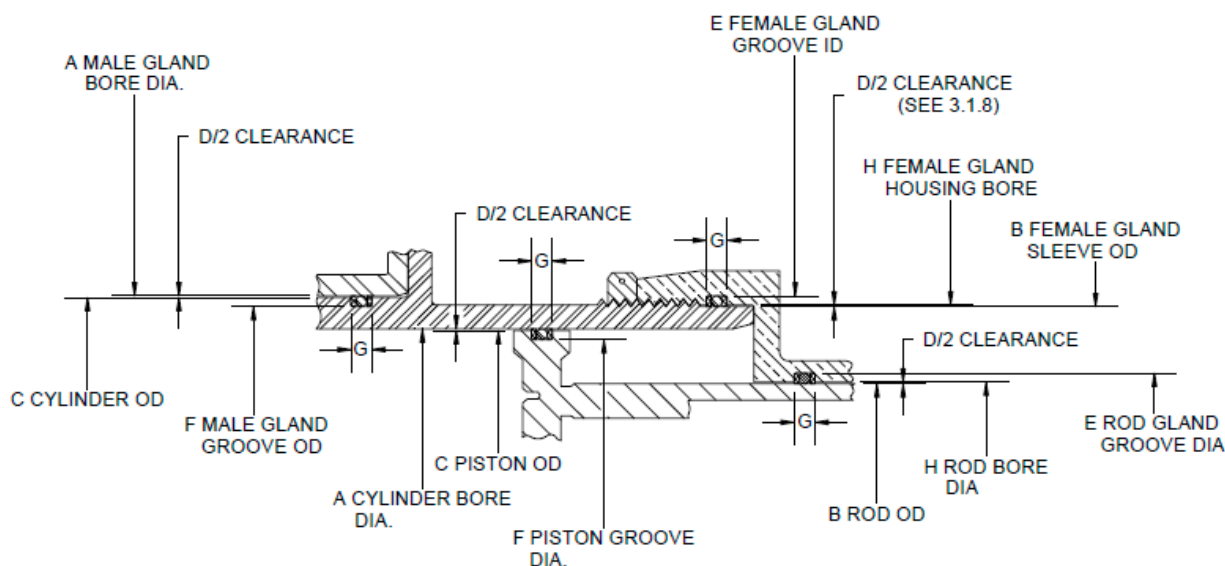


FIGURE 1 – KEY DIMENSIONS FOR GLAND DESIGN - AS4716, AS5857

BACKUP RING DIMENSIONS: The key hardware dimensions for backup rings, as defined in AS5781, AS5782, AS5860 and AS5861, are as shown in Figures 2 and 3.

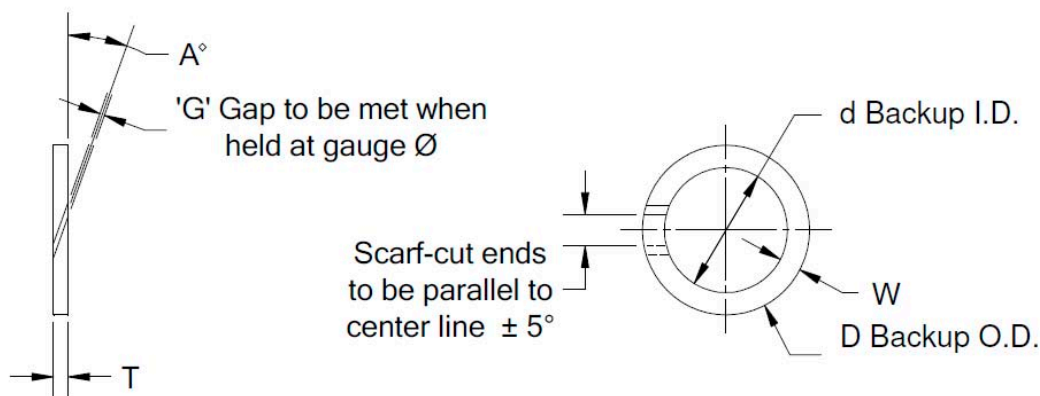


FIGURE 2 - KEY DIMENSIONS FOR SCARF-CUT BACKUP RING - AS5781, AS5860

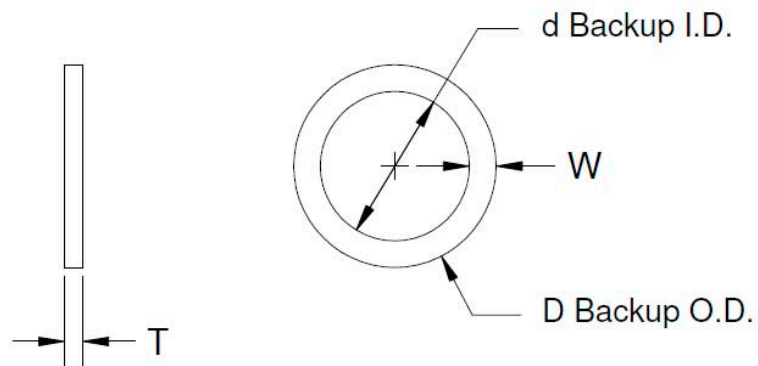


FIGURE 3 - KEY DIMENSIONS FOR SOLID BACKUP RING - AS5782, AS5861

BACKUP VOLUME: This is the volume of the backup ring and is calculated at ambient temperature and at the maximum operating temperature of 275 °F (135 °C) for gland occupancy purposes.

RACETRACK SHAPE: This is the shape of a squeezed O-ring cross section as shown in Figures 4, 5, and 7 (Refer to 3.1.1).

2.3 Abbreviations

2.3.1 General

B/U	Backup Ring
C/X	Cross Section
I.D.	Inside Diameter
Nom	Nominal dimension
O.D.	Outside Diameter
PTFE	Polytetrafluoroethylene
t	Temperature
Tol	Tolerance dimension
Typ	Typical

2.3.2 Abbreviations used in Equations

2.3.2.1 General Abbreviations

BV	Backup Volume
C	O-ring I.D.
Y	O ring radius to mean of cross-section
H	O-ring cross section radius
G	Maximum gap at scarf-cut when held against gauge
G ₁	Groove width, one backup

G_2	Groove width, two backup
GAR1	Groove cross-section area perpendicular sidewalls, including corner radii, 1 backup groove width
GAR2	Groove cross-section area perpendicular sidewalls, including corner radii, 2 backup groove width
GV1	Groove volume perpendicular sidewalls, excluding corner radii, 1 backup groove width
GV2	Groove volume perpendicular sidewalls, excluding corner radii, 2 backup groove width
GVR1	Groove volume perpendicular sidewalls, including corner radii, 1 backup groove width
GVR2	Groove volume perpendicular sidewalls, including corner radii, 2 backup groove width
H	O-ring radius to center of C/X
ℓ	Length of flat on racetrack shape of squeezed O-ring cross section
L	Overall axial length of O-ring when installed in compressed condition
L_e	Overall axial length of O-ring when installed in compressed condition and at temperature due to thermal expansion
P	O-ring I.D. (maximum)
PS	Radial groove depth
q	Cross section of O-ring when in compressed installed condition
Q	O-ring cross section diameter in the free condition
R	Groove corner radius
RA2	Area of two (2) groove corner radii
RV2	Volume of two (2) groove corner radii
T	Backup thickness (axial length)
T_{Exp}	Backup thickness (max) at overlapped scarf cut when expanded at 275 °F (135 °C)
V	O-ring Volume (maximum tolerances)
V_E	O-ring Volume, maximum, at elevated temperature due to thermal expansion
W	Backup ring radial width
X	Backup ring shrink due to thermal contraction
Y	O-ring section radius
Z_1	Axial clearance in groove with O-ring and 1 backup installed
Z_2	Axial clearance in groove with O-ring and 2 backups installed

2.3.2.2 Abbreviations Specific to Piston Type Applications

$\angle A$	Scarf-cut angle measured from face of backup ring
A	Cylinder bore diameter
d	Backup inside diameter, solid backups/scarf cut backups
D	Backup outside diameter, solid backups / scarf cut backups
D_{Inc}	Increase in Backup O.D. to maintain 50% lap requirement
F	Groove diameter
L_1	Scarf-cut circumferential length, measured at part O.D.
L_2	Scarf-cut circumferential length, measured at part I.D.
N	Cylinder increased diameter due to breathing

2.3.2.3 Abbreviations Specific to Rod Type Applications

$\angle A$	Scarf-cut angle in relation to face of backup ring
B	Rod diameter
d	Backup inside diameter, solid backups / scarf cut backups
D	Backup outside diameter, solid backups / scarf cut backups
E	Rod gland groove diameter
L_2	Scarf-cut circumferential length, measured at part I.D.

3. DESIGN CALCULATIONS FOR BACKUP RINGS

NOTE: Some equations are repeated in this section

3.1 Backup Ring Thickness “T” (Axial Dimension)

When being created, the committee charter for thickness (axial length) for all backup rings to AS5781, AS5782, AS5860 and AS5861 was to at least match some popular manufacturer standards. This was followed as closely as possible while maintaining a volume fill below 100% at maximum operating temperature and using PTFE and elastomer materials with the highest linear coefficient of thermal expansion for worst case conditions.

T_{Nom} = Nominal thickness of the backup ring

Tolerance on thickness for all Dash Sizes = ± 0.002 in (± 0.051 mm)

Table 1 provides the nominal thicknesses of the SAE standard backup rings.

TABLE 1 - T DIMENSIONS FOR BACKUP RINGS BY SPECIFICATION AND BY DASH SIZE SERIES

BACKUP RING SPECIFICATION	DASH SIZE SERIES	T_{Nom} (inches)	T_{Nom} (mm)
AS5781, AS5782	000	0.050	1.27
	100	0.058	1.47
	200	0.062	1.57
	300	0.088	2.24
	400	0.129	3.28
AS5860, AS5861	000	0.054	1.37
	100	0.058	1.47
	200	0.062	1.57
	300	0.088	2.24
	400	0.128	3.25

It should be noted that the T_{Nom} dimension is different for AS5781, AS5782 in some cases compared to AS5860, AS5861. The reason for this is that AS5857 uses a higher squeeze than AS4716, which produces a longer axial length in the O-ring when installed (squeezed). While in most cases AS5857 uses the same groove widths as AS4716, some groove widths in AS5857 are increased in order to prevent overoccupancy (more than 100%) at maximum operating temperature.

3.1.1 Axial Clearance Calculations

Calculate the axial clearance for solid backups and scarf cut backups at positions other than at scarf-cut lap.

Refer to Figures 4 and 5

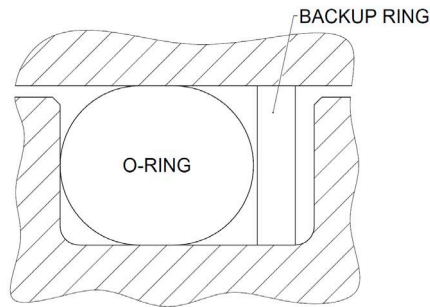


FIGURE 4 - COMPRESSED O-RING WITH SINGLE BACKUP IN PISTON SEAL GLAND

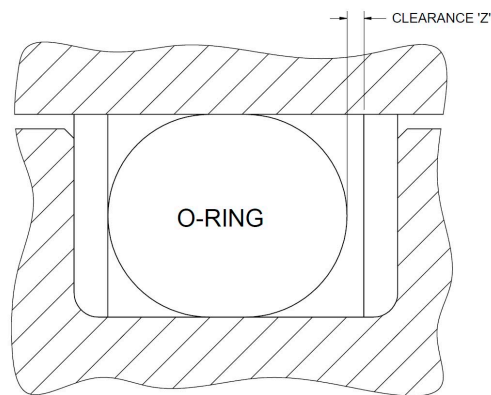


FIGURE 5 - COMPRESSED O-RING WITH TWO BACKUPS IN PISTON SEAL GLAND

For One Backup Width:

Clearance = Groove Width – (Axial Length of O-ring + Axial Length of One Backup)

$$\text{Clearance } Z_1 = G_{1\min} - (L_{\max} + T_{\max}) \quad (\text{Eq. 1})$$

For Two Backups Width:

Clearance = Groove Width – (Axial Length of O-ring + Axial Length of Two Backups)

$$\text{Clearance } Z_2 = G_{2\min} - (L_{\max} + 2T_{\max}) \quad (\text{Eq. 2})$$

3.1.1.1 Calculate the Overall Length of the Squeezed O-Ring

Refer to Figures 6 and 7

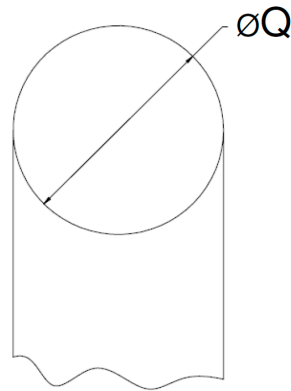


FIGURE 6 - O-RING IN FREE CONDITION

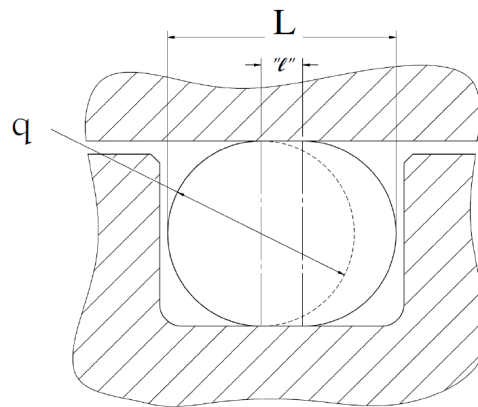


FIGURE 7 - COMPRESSED O-RING IN ZERO BACKUP WIDTH PISTON SEAL GLAND

$$\text{Area of O-ring cross section} = \frac{\pi Q^2}{4} \quad (\text{Eq. 3})$$

Assume that when squeezed, the O-ring maintains the same total cross sectional area as in the free condition, then

$$\frac{\pi Q^2}{4} = \frac{\pi q^2}{4} + q \ell \quad (\text{Eq. 4})$$

and

$$L = q + \ell \quad (\text{Eq. 5})$$

From the above, it can be deduced that the O-ring Overall Length (L) when squeezed is:

$$L = \frac{\pi}{4} \left[\frac{Q_{\text{Max}}^2}{q} - q \right] + q \quad (\text{Eq. 6})$$

NOTE: Use maximum O-ring Q_{Max} cross section tolerance diameter dimension for worst case condition

3.1.1.2 Established Groove Widths

As a result of calculations for the AS5860 Volumetric Gland Occupancy, the groove widths for AS5857 are larger from those of AS4716 in order to accommodate the more highly squeezed O-ring while maintaining backups of sufficient thickness (axial length) to maintain integrity of design.

Tables 2A, 2B, 2C, and 2D below list the groove widths for comparison purposes.

TABLE 2A – AS 4716 STANDARD GROOVE WIDTH FOR ZERO, ONE, AND TWO BACKUP IN INCHES

GLAND AND AS568 DASH NO	O-RING CROSS SECTION W MIN	O-RING CROSS SECTION W MAX	GROOVE WIDTH G ₀ NO BACKUP RING MIN	GROOVE WIDTH G ₀ NO BACKUP RING MAX	GROOVE WIDTH G ₁ ONE BACKUP RING MIN	GROOVE WIDTH G ₁ ONE BACKUP RING MAX	GROOVE WIDTH G ₂ TWO BACKUP RINGS MIN	GROOVE WIDTH G ₂ TWO BACKUP RINGS MAX
001	0.037	0.043	0.070	0.075	--	--	--	--
002	0.047	0.053	0.077	0.082	--	--	--	--
003	0.057	0.063	0.088	0.093	--	--	--	--
004 to 007	0.067	0.073	0.098	0.103	0.154	0.164	0.210	0.220
008 to 028	0.067	0.073	0.094	0.099	0.150	0.160	0.207	0.217
104 to 149	0.100	0.106	0.141	0.151	0.183	0.193	0.245	0.255
210 to 247	0.135	0.143	0.188	0.198	0.235	0.245	0.304	0.314
325 to 349	0.205	0.215	0.281	0.291	0.334	0.344	0.424	0.434
424 to 460	0.269	0.281	0.375	0.385	0.475	0.485	0.579	0.589

TABLE 2B – AS 4716 STANDARD GLAND WIDTH FOR ZERO, ONE, AND TWO BACKUP IN MILLIMETERS

GLAND AND AS568 DASH NO	O-RING CROSS SECTION W MIN	O-RING CROSS SECTION W MAX	GROOVE WIDTH G ₀ NO BACKUP RING MIN	GROOVE WIDTH G ₀ NO BACKUP RING MAX	GROOVE WIDTH G ₁ ONE BACKUP RING MIN	GROOVE WIDTH G ₁ ONE BACKUP RING MAX	GROOVE WIDTH G ₂ TWO BACKUP RINGS MIN	GROOVE WIDTH G ₂ TWO BACKUP RINGS MAX
001	0.94	1.09	1.78	1.91	--	--	--	--
002	1.19	1.35	1.96	2.08	--	--	--	--
003	1.45	1.60	2.24	2.36	--	--	--	--
004 to 007	1.70	1.85	2.49	2.62	3.91	4.17	5.33	5.59
008 to 028	1.70	1.85	2.39	2.51	3.81	4.06	5.26	5.51
104 to 149	2.54	2.69	3.58	3.84	4.65	4.90	6.22	6.48
210 to 247	3.43	3.63	4.78	5.03	5.97	6.22	7.72	7.98
325 to 349	5.21	5.46	7.14	7.39	8.48	8.74	10.77	11.02
424 to 460	6.83	7.14	9.53	9.78	12.07	12.32	14.71	14.96

TABLE 2C – AS5857 STANDARD GROOVE WIDTH FOR ZERO, ONE, AND TWO BACKUP IN INCHES

GLAND AND AS568 DASH NO	O-RING CROSS SECTION W MIN	O-RING CROSS SECTION W MAX	GROOVE WIDTH G ₀ NO BACKUP RING MIN	GROOVE WIDTH G ₀ NO BACKUP RING MAX	GROOVE WIDTH G ₁ ONE BACKUP RING MIN	GROOVE WIDTH G ₁ ONE BACKUP RING MAX	GROOVE WIDTH G ₂ TWO BACKUP RINGS MIN	GROOVE WIDTH G ₂ TWO BACKUP RINGS MAX
001	0.037	0.043	0.090	0.095	--	--	--	--
002	0.047	0.053	0.095	0.100	--	--	--	--
003	0.057	0.063	0.105	0.110	--	--	--	--
004 to 007	0.067	0.073	0.115	0.120	0.174	0.184	0.230	0.240
008 to 028	0.067	0.073	0.105	0.110	0.164	0.174	0.220	0.230
104 to 109	0.100	0.106	0.150	0.160	0.210	0.220	0.275	0.285
110 to 149	0.100	0.106	0.140	0.150	0.200	0.210	0.265	0.275
210 to 247	0.135	0.143	0.185	0.195	0.250	0.260	0.320	0.330
325 to 349	0.205	0.215	0.270	0.280	0.360	0.370	0.455	0.465
424 to 460	0.269	0.281	0.345	0.355	0.475	0.485	0.510	0.620

TABLE 2D – AS5857 STANDARD GLAND WIDTH FOR ZERO, ONE, AND TWO BACKUP IN MILLIMETERS

GLAND AND AS568 DASH NO	O-RING CROSS SECTION W MIN	O-RING CROSS SECTION W MAX	GROOVE WIDTH G ₀ NO BACKUP RING MIN	GROOVE WIDTH G ₀ NO BACKUP RING MAX	GROOVE WIDTH G ₁ ONE BACKUP RING MIN	GROOVE WIDTH G ₁ ONE BACKUP RING MAX	GROOVE WIDTH G ₂ TWO BACKUP RINGS MIN	GROOVE WIDTH G ₂ TWO BACKUP RINGS MAX
001	0.94	1.09	2.29	2.41	--	--	--	--
002	1.19	1.35	2.41	2.54	--	--	--	--
003	1.45	1.60	2.67	2.79	--	--	--	--
004 to 007	1.70	1.85	2.92	3.05	4.42	4.67	5.84	6.10
008 to 028	1.70	1.85	2.67	2.79	4.17	4.42	5.59	5.84
104 to 109	2.54	2.69	3.81	4.06	5.33	5.59	6.99	7.24
110 to 149	2.54	2.69	3.56	3.81	5.08	5.33	6.73	6.99
210 to 247	3.43	3.63	4.70	4.95	6.35	6.60	8.13	8.38
325 to 349	5.21	5.46	6.86	7.11	9.14	9.40	11.56	11.81
424 to 460	6.83	7.14	8.76	9.02	12.07	12.32	12.95	15.75

3.2 Radial Wall Dimension of Backup Rings “W” dimension

3.2.1 Piston Backup Rings

For piston grooves, the minimum radial groove depth (PS_{Min}) is:

$$PS_{Min} = \frac{(A_{Min} - F_{Max})}{2} \quad (\text{Eq. 7})$$

NOTE: The piston and cylinder are assumed to be concentric