



AEROSPACE INFORMATION REPORT

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Superseding AIR1362C

Aerospace Hydraulic Fluids Physical Properties

RATIONALE

Table 10 typical flash point temperatures have been corrected.

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1. SCOPE

This SAE Aerospace Information Report (AIR) presents data on hydraulic fluids which are of interest to detail designers of hydraulic systems and components for aerospace flight vehicles.

The data pertains to fluids conforming to the following specifications:

- MIL-PRF-5606
- MIL-H-8446
- MIL-PRF-27601 (canceled) MIL-PRF-27601 has been canceled without replacement and the data presented herein is for information purposes only.
- MIL-PRF-83282
- MIL-H-53119
- MIL-PRF-87257
- AS1241 Type IV, Classes 1 and 2, and Type V

2. 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 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR81	Importance of Physical and Chemical Properties of Aircraft Hydraulic Fluids
AIR1657	Handbook of Hydraulic Metric Calculations
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

2.2 U.S. Government Publications

Copies of these documents are available online at <http://quicksearch.dla.mil>.

MIL-PRF-5606	Military Specification Hydraulic Fluid, Petroleum Base; Aircraft, Missile and Ordnance, NATO Code Number H-515 (Inactive for New Design)
MIL-H-8446	Military Specification Hydraulic Fluid, Nonpetroleum Base; Aircraft (Canceled)
MIL-PRF-27601	Performance Specification Hydraulic Fluid, Fire Resistant, Hydrogenated Polyalphaolefin Base, High Temperature, Flight Vehicle, Metric
MIL-PRF-83282	Performance Specification Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537

- MIL-H-53119 Performance Specification Hydraulic Fluid, Nonflammable, Chlorotrifluoroethylene Base (Inactive for New Design)
- MIL-PRF-87257 Military Specification Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile, NATO Code Number H-538

3. DESCRIPTION OF PROPERTIES

Hydraulic fluids have many physical and chemical properties (Table 1) which must be considered in the design of a hydraulic system as follows:

Table 1 – Physical and chemical properties

Property	Effect
1. Bulk Modulus	System stiffness
2. Viscosity	Power losses
3. Density	System weight
4. Specific Heat	Thermal characteristics
5. Thermal Conductivity	Heat exchanger design
6. Thermal Expansion	Reservoir design
7. Fire Resistance	Safety and survivability
8. Chemical Stability	Formation of breakdown products
9. Thermal Stability	Deterioration of fluid properties
10. Shear Stability	Loss of lubricity and viscosity
11. Hydrolytic Stability	Corrosion
12. Lubricity	Component wear
13. Compatibility	System materials
14. Volatility	Cavitation and evaporation
15. Toxicity	Safety
16. Foaming	Cavitation and system stiffness

NOTE: The above listing sequence has no bearing on relative importance. Properties 1 through 7 have specific numerical values which are required in detail design and analysis work; data covering these properties are given in the document. Properties 8 through 16 are important considerations in the selection of a hydraulic fluid for a specific application, but numerical values associated with these properties are not usually required in system design. Data on Properties 8 through 16 are not included in this document.

Table 2 contains the types of hydraulic fluid considered to be most applicable to air vehicles:

Table 2 – Hydraulic fluid types

Fluid Type	Operating Temperature	Specification
Petroleum base with polymeric additives	-65 to 275 °F (-54 to 135 °C)	MIL-PRF-5606
Silicate ester	-65 to 400 °F (-54 to 204 °C)	MIL-H-8446
Synthetic hydrocarbon fire resistant	-40 to 550 °F (-40 to 288 °C)	MIL-PRF-27601
Synthetic hydrocarbon, fire resistant	-40 to 401 °F (-40 to 205 °C)	MIL-PRF-83282
Nonflammable, chloro-trifluoroethylene base	-65 to 275 °F (-54 to 135 °C)	MIL-H-53119
Synthetic hydrocarbon, fire resistant	-65 to 275 °F (-54 to 135 °C)	MIL-PRF-87257
Phosphate ester, fire resistant	-65 to 225 °F (-54 to 107 °C)	AS1241, Type IV, Classes 1 and 2
	-65 to 275 °F (-54 to 135 °C)	AS1241, Type V

NOTE: AS1241, Type IV phosphate ester fluid is used in two different versions, Class 1, a low density (specific gravity 0.990 to 1.020), and Class 2, a high density (specific gravity 1.020 to 1.066). Type V phosphate ester is a higher temperature fluid, with specific gravity 0.97 to 1.02. Where available, data for both classes and types are provided.

Operating conditions can cause changes in the physical properties of a hydraulic fluid. Temperature and pressure, in particular, have significant influences on fluid viscosity and bulk modulus. The detail designer requires data for specific operating conditions, but these data are often not readily available. This results in designers acquiring, through various means, a personal file of hydraulic fluid properties.

The intent of this document is to encourage the use of standardized design information. Fluid specifications provide for variations in properties which can result from differences in manufacturing processes or base stocks used. The data presented herein are considered to be nominal values.

4. HYDRAULIC FLUID PROPERTIES

4.1 Bulk Modulus

Bulk modulus is a term used to denote the ability of a fluid to resist volumetric reduction caused by applied pressure and is an important parameter in the design of hydraulic servo systems. Interaction of fluid compressibility with the mass of the mechanical parts and load produces a natural frequency in hydraulic systems. This resonance is often the chief limitation to dynamic performance and is approximately proportional to the square root of the fluid bulk modulus. Pressure is generally measured as gauge pressure while all equations in this document use absolute pressure.

There are several different types of bulk moduli; selection of the proper modulus is based on the function being performed. Functions that occur rapidly, with little chance for heat transfer into or out of the system, require adiabatic moduli; examples include hydraulic pumps, motors, and rapidly oscillating servo actuators. Functions that occur slowly or with constant fluid temperature require isothermal moduli; this modulus has limited application to air vehicle hydraulic systems. Pressure excursion magnitude is also a factor in modulus selection. Large excursions, for example in pumps and motors, require the use of secant moduli; small pressure fluctuations around a quiescent level, as in oscillating servo actuators, require the use of tangent moduli. Bulk modulus is the reciprocal of fluid compressibility and is generally expressed in pounds per square inch (psi) (Pascal (Pa)). The most commonly used moduli are summarized in Table 3:

Table 3 - Commonly used bulk moduli

Function	Pressure Excursion	Bulk Modulus	Application
Dynamic	Small ¹	Adiabatic Tangent	Design of servo systems and actuators
Dynamic	Large ²	Adiabatic Secant	Design of hydraulic pumps
Static	Small	Isothermal Tangent	Limited use in air vehicle system design
Static	Large	Isothermal Secant	Limited use in air vehicle systems design

¹ Less than 10% of system pressure (approximately).

² More than 80% of system pressure (approximately).

Bulk modulus is defined by:

$$\beta_t = -V \frac{\partial P}{\partial V} \quad (\text{Eq. 1})$$

and,

$$\beta_s = -V_o \left(\frac{P_o - P}{V_o - V} \right) \quad (\text{Eq. 2})$$

where:

β_t = Adiabatic tangent bulk modulus, Pa

β_s = Adiabatic secant bulk modulus, Pa

P = Pressure, Pa

V = Volume at pressure P, ft³ (m³)

P_o = Reference pressure, usually atmospheric, Pa

V_o = Volume at pressure P_o, ft³ (m³)

Equation 1 is the thermodynamic definition of bulk modulus and represents the true rate of volumetric change at the pressure of "interest". Equation 2 defines a "mean" bulk modulus and represents the volumetric change with pressure from atmospheric to the pressure of "interest". Both moduli can be determined under isothermal or adiabatic conditions.

Two methods used for measuring bulk modulus are the pressure-volume-temperature method, which gives isothermal secant information and the sonic method which yields adiabatic tangent data.

Relationships between the moduli are:

$$\frac{\beta_{at}}{\beta_{it}} = \gamma$$

β_{it} at pressure P is approximately equal to β_{is} at pressure 2P

$$\beta_{at} = \rho c^2 \quad (\text{Eq. 3})$$

where:

β_{at} = Adiabatic tangent bulk modulus, Pa

β_{it} = Isothermal tangent bulk modulus, Pa

β_{is} = Isothermal secant bulk modulus, Pa

$$\gamma = \frac{c_p}{c_v}$$

c_p = Specific heat at constant pressure, J/(kg K)

c_v = Specific heat at constant volume, J/(kg K)

ρ = Mass density, kg/m³

c = Velocity of sound in the fluid, m/s

Bulk modulus can be substantially lowered by the presence of entrained air (free bubbles) in the fluid. Dissolved air has a minor effect in reducing bulk modulus. The amount of air which can be dissolved in hydraulic fluids is approximately proportional to the pressure level. The time required to achieve equilibrium conditions may prevent complete dissolution in some cases. Generally, when the operating pressure exceeds the saturation pressure, bulk modulus degradation due to air is small.

The bulk modulus data (Table 4) presented in this document cover temperatures from 0 to 300 °F (0 to +149 °C) at pressure from 0 to 10000 psi (0 to 69 mega Pascal (MPa)).

Table 4 – List of bulk modulus figures

Figure No.	Bulk Modulus	Hydraulic Fluid
1	Adiabatic Tangent	MIL-PRF-5606
2	Adiabatic Tangent	MIL-H-8446
3	Adiabatic Tangent	MIL-PRF-27601
4	Adiabatic Tangent	MIL-PRF-83282
5	Adiabatic Tangent	MIL-H-53119
6	Adiabatic Tangent	MIL-PRF-87257
7	Adiabatic Secant	MIL-PRF-5606
8	Adiabatic Secant	MIL-H-8446
9	Adiabatic Secant	MIL-PRF-27601
10	Adiabatic Secant	MIL-PRF-83282
11	Adiabatic Secant	MIL-PRF-87257
12	Isothermal Secant	MIL-PRF-5606
13	Isothermal Secant	MIL-H-8446
14	Isothermal Secant	MIL-PRF-27601
15	Isothermal Secant	MIL-PRF-83282
16	Isothermal Secant	MIL-H-53119
17	Isothermal Secant	MIL-PRF-87257
18	Isothermal Secant	AS1241, Type IV, Class 1

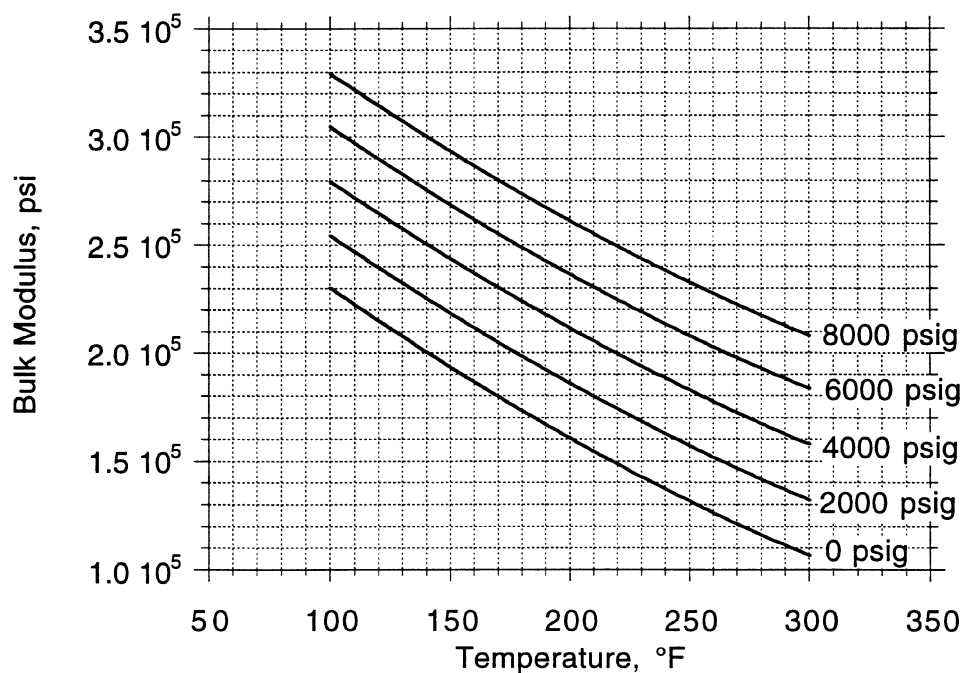


Figure 1A - Adiabatic tangent bulk modulus of MIL-PRF-5606 (English units)

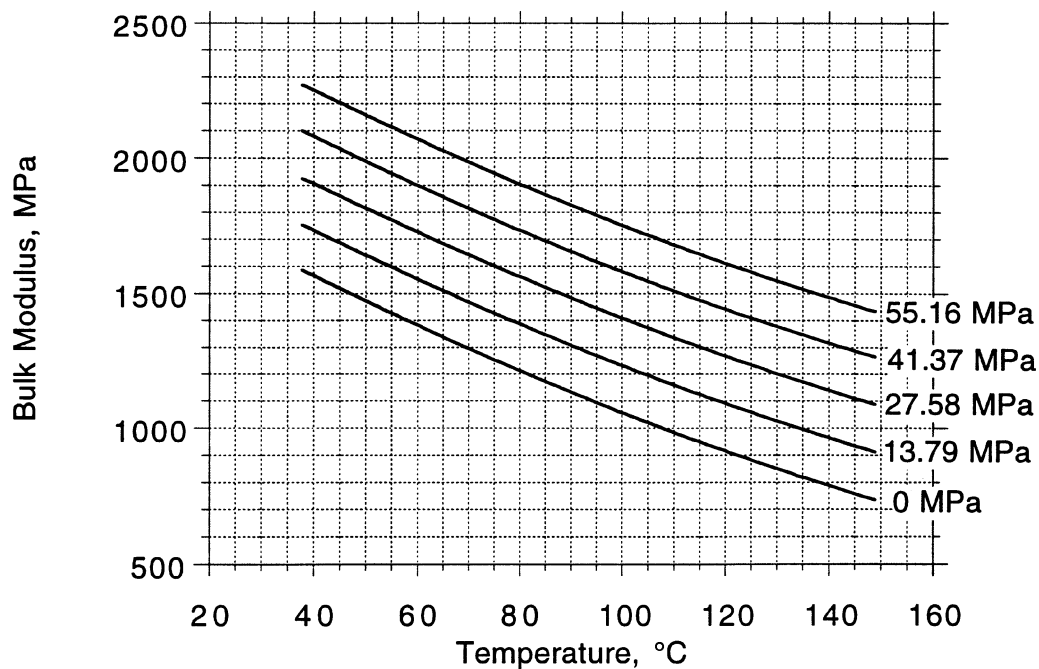


Figure 1B - Adiabatic tangent bulk modulus of MIL-PRF-5606 (metric units)

Figure 1

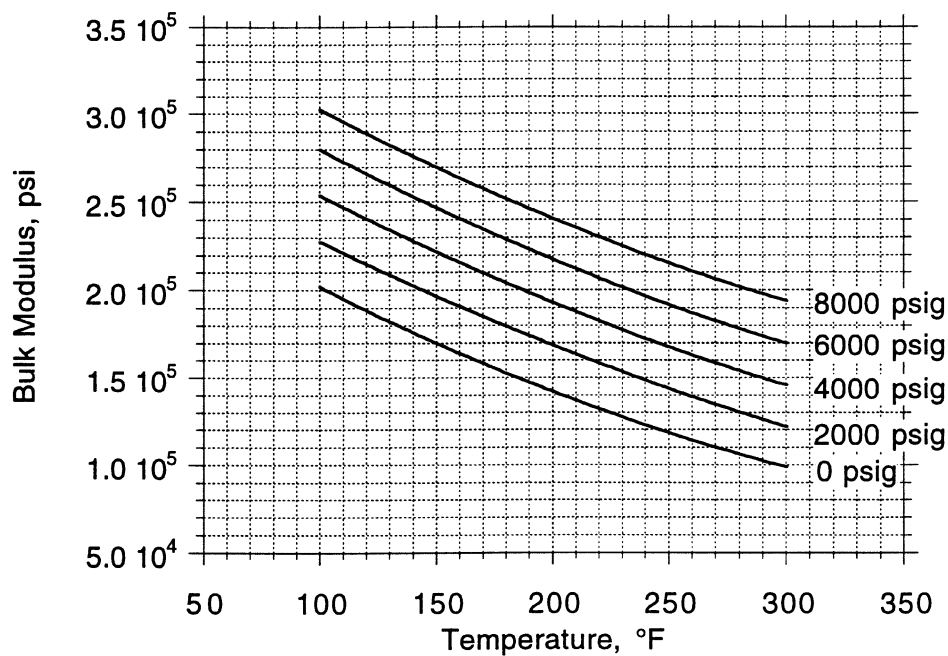


Figure 2A - Adiabatic tangent bulk modulus of MIL-H-8446 (English units)

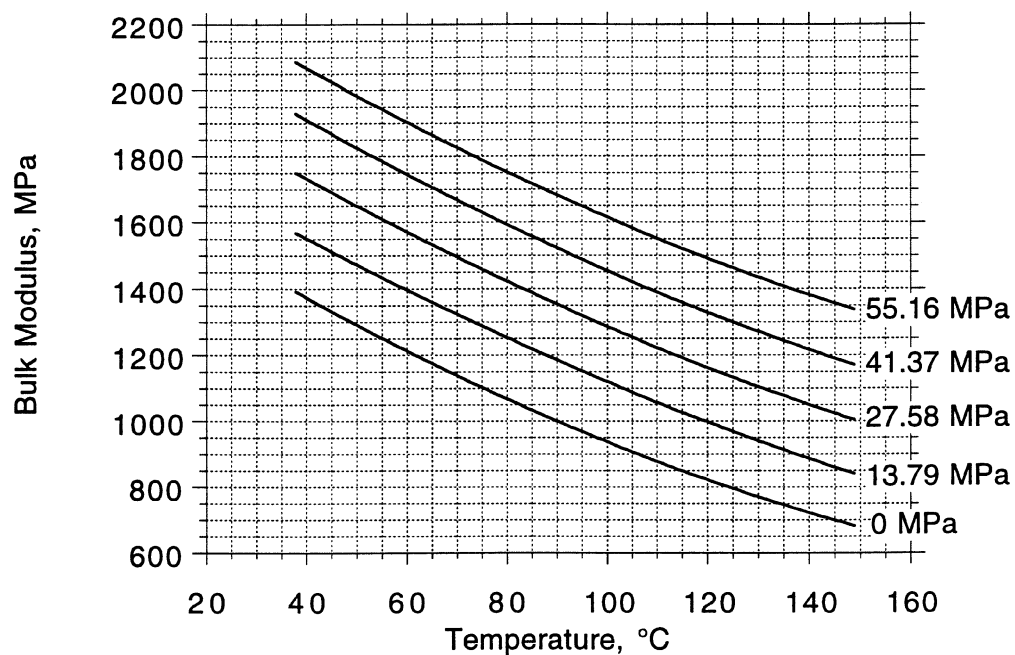


Figure 2B - Adiabatic tangent bulk modulus of MIL-H-8446 (metric units)

Figure 2

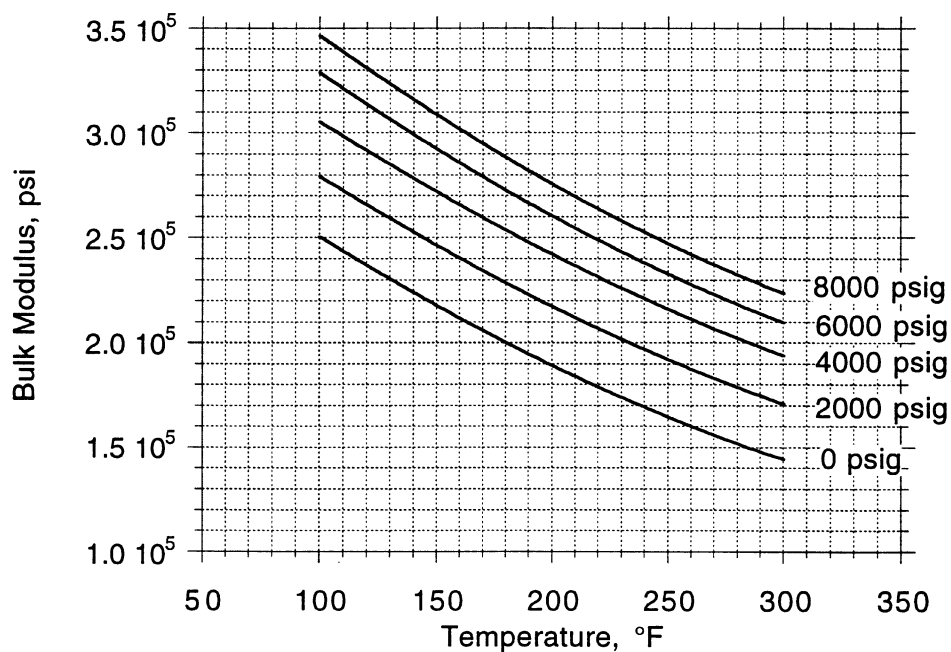


Figure 3A - Adiabatic tangent bulk modulus of MIL-PRF-27601 (English units)

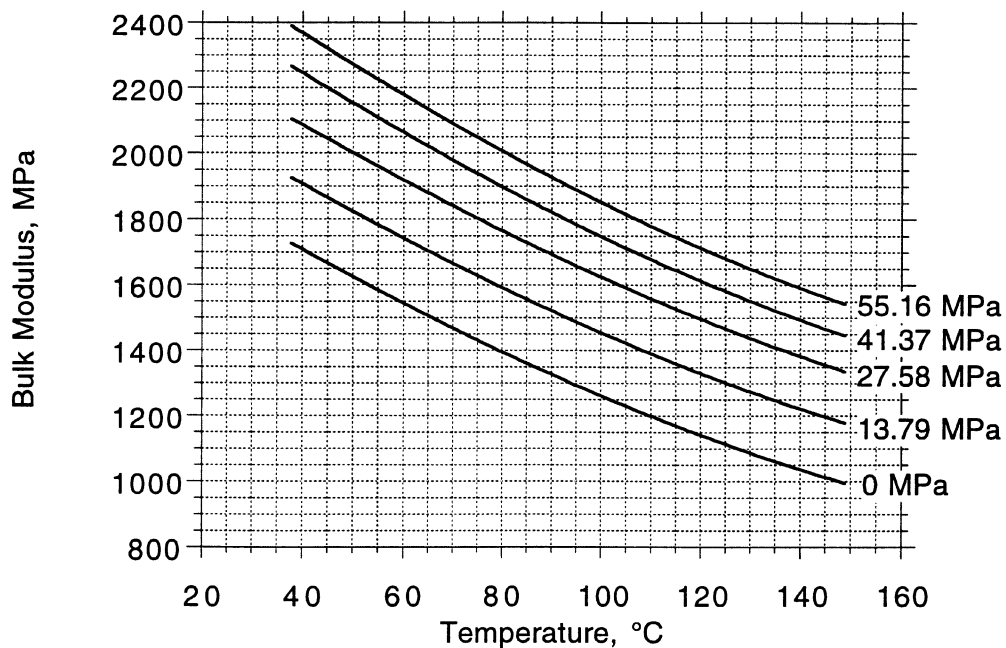


Figure 3B - Adiabatic tangent bulk modulus of MIL-PRF-27601 (metric units)

Figure 3

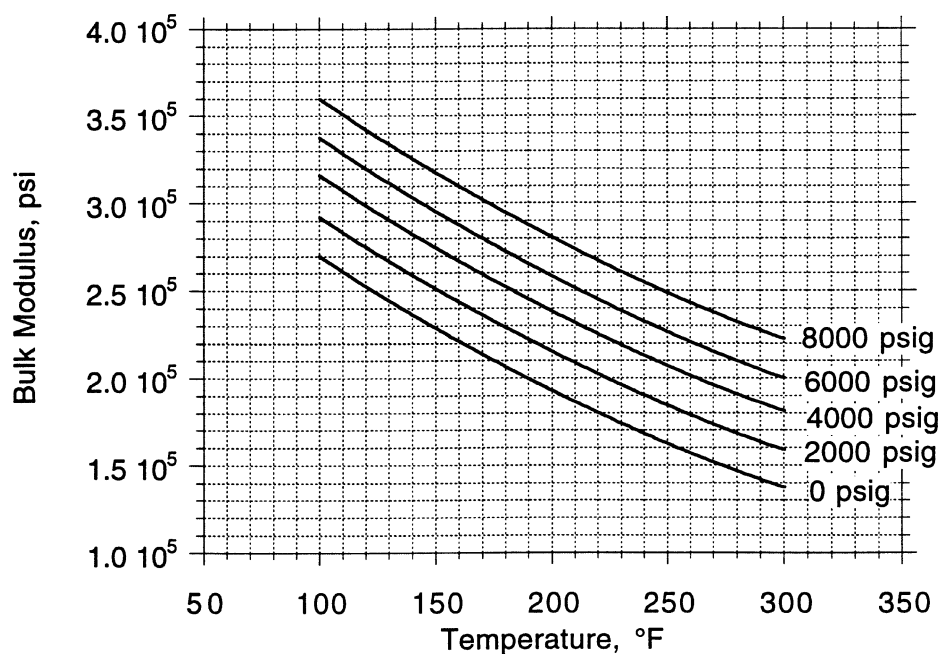


Figure 4A - Adiabatic tangent bulk modulus of MIL-PRF-83282 (English units)

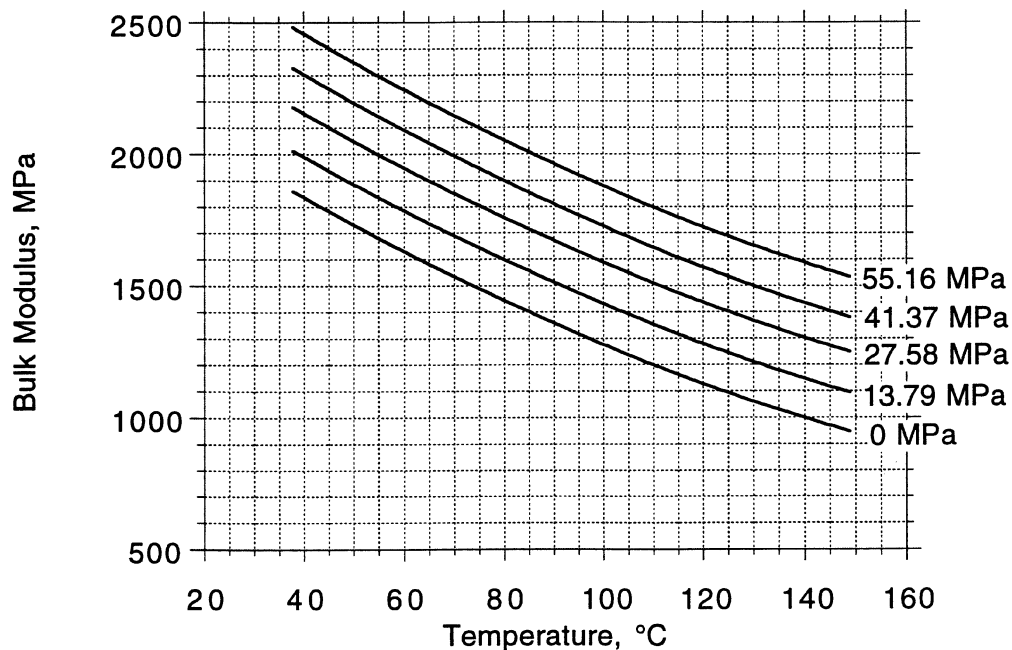


Figure 4B - Adiabatic tangent bulk modulus of MIL-PRF-83282 (metric units)

Figure 4

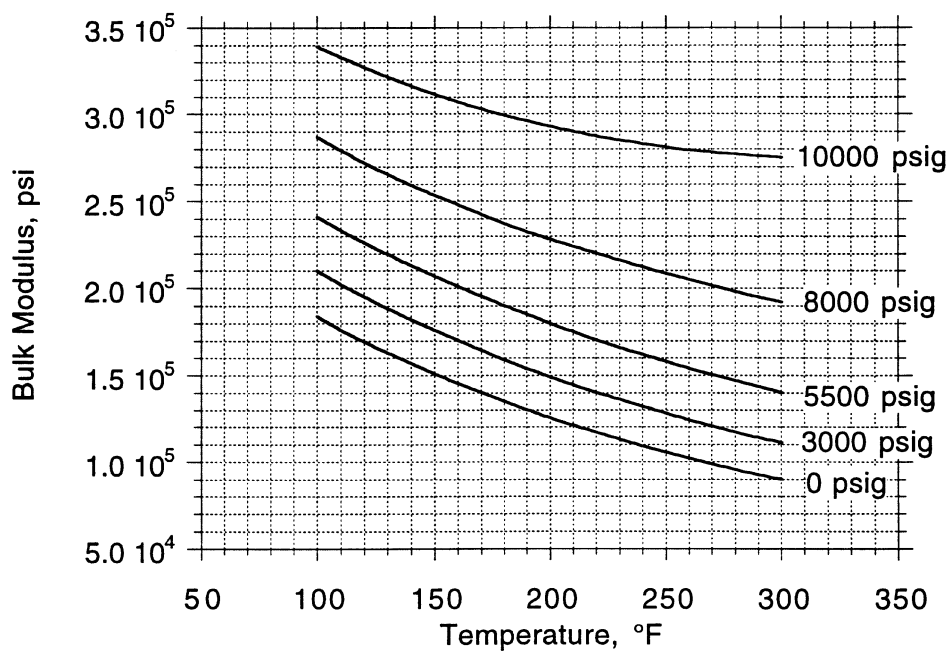


Figure 5A - Adiabatic tangent bulk modulus of MIL-H-53119 (English units)

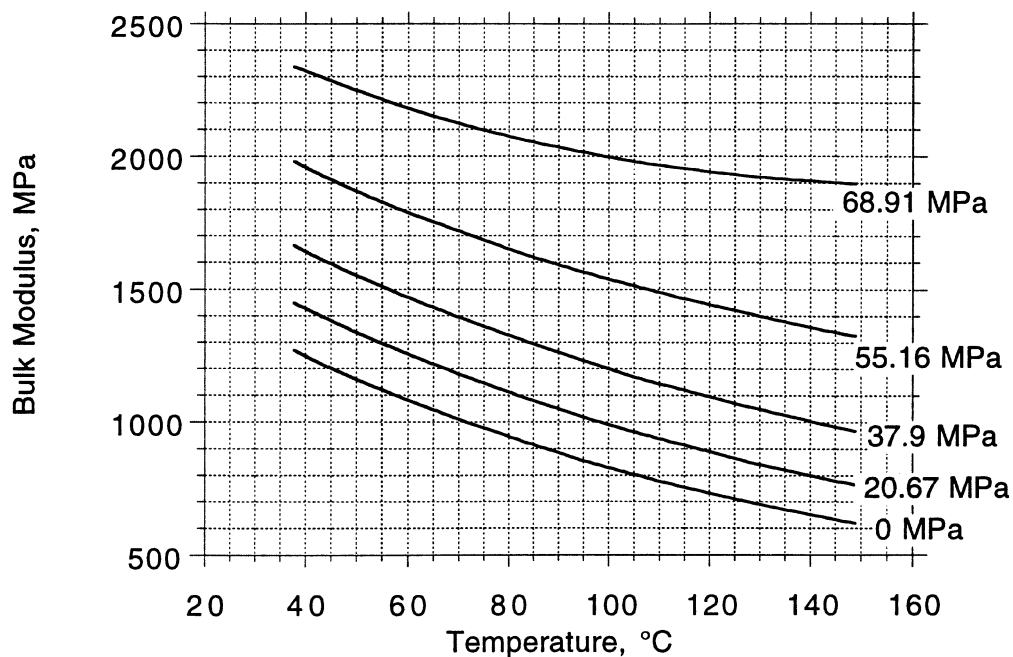


Figure 5B - Adiabatic tangent bulk modulus of MIL-H-53119 (metric units)

Figure 5

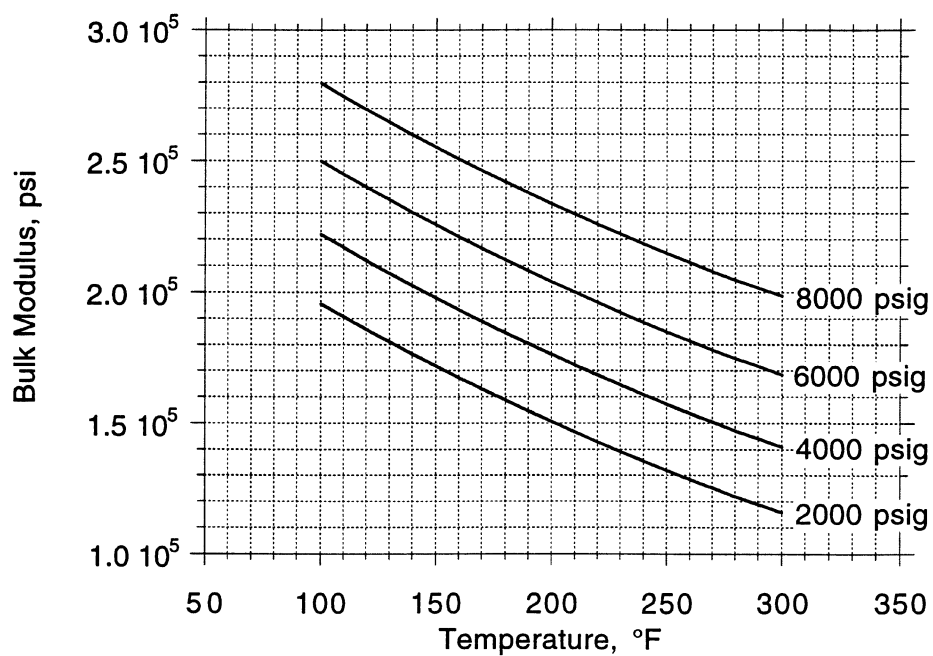


Figure 6A - Adiabatic tangent bulk modulus of MIL-PRF-87257 (English units)

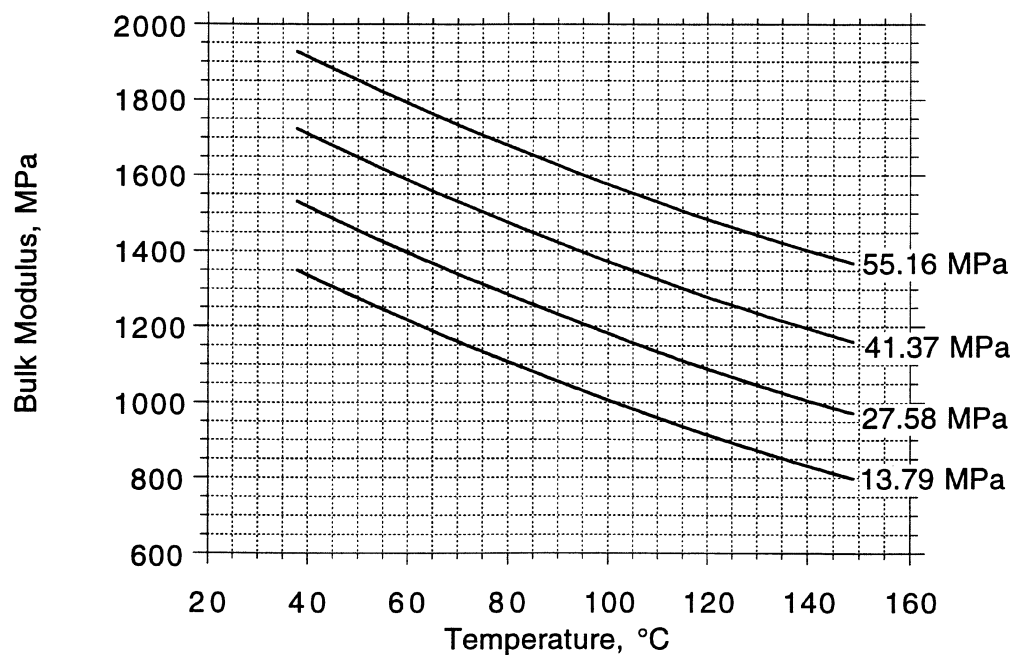


Figure 6B - Adiabatic tangent bulk modulus of MIL-PRF-87257 (metric units)

Figure 6

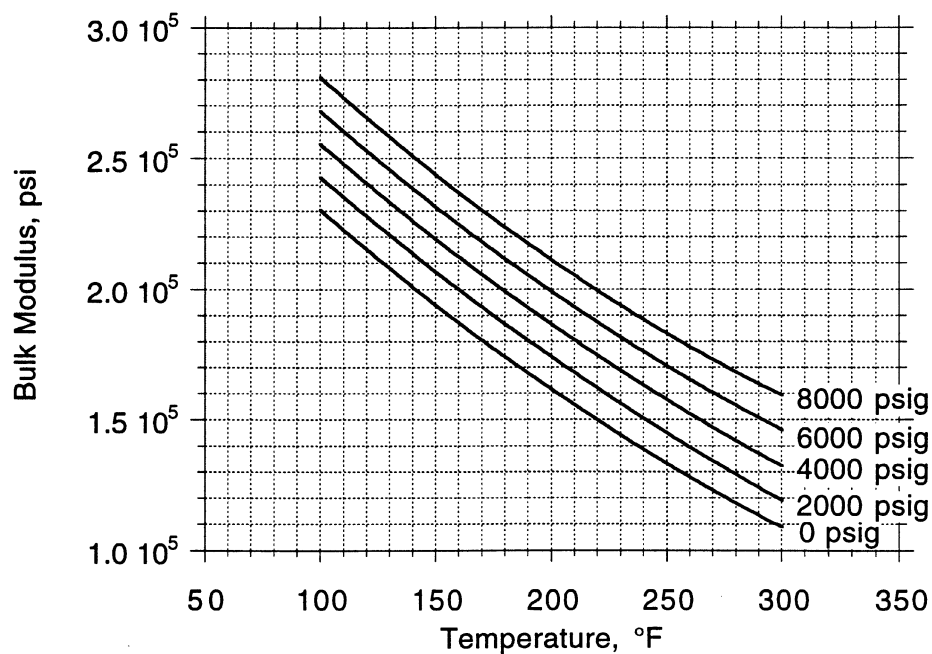


Figure 7A - Adiabatic secant bulk modulus of MIL-PRF-5606 (English units)

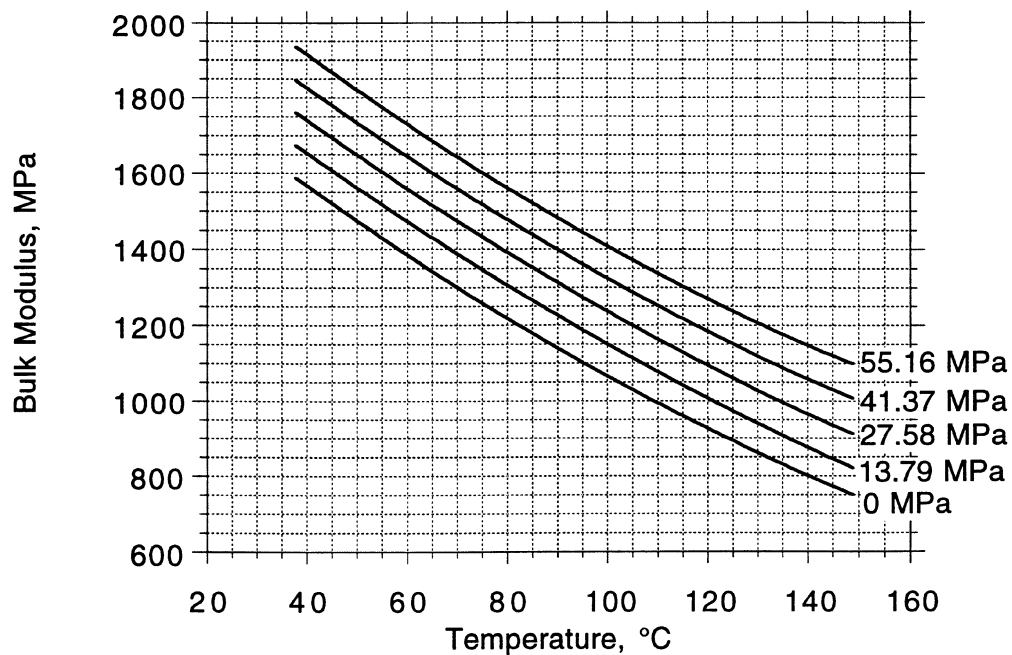


Figure 7B - Adiabatic secant bulk modulus of MIL-PRF-5606 (metric units)

Figure 7

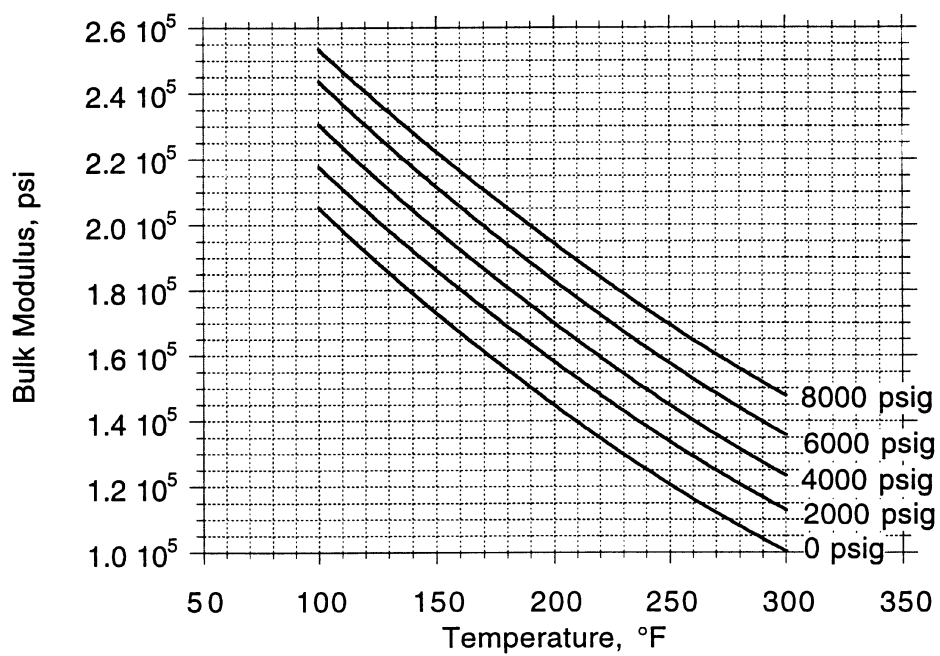


Figure 8A - Adiabatic secant bulk modulus of MIL-H-8446 (English units)

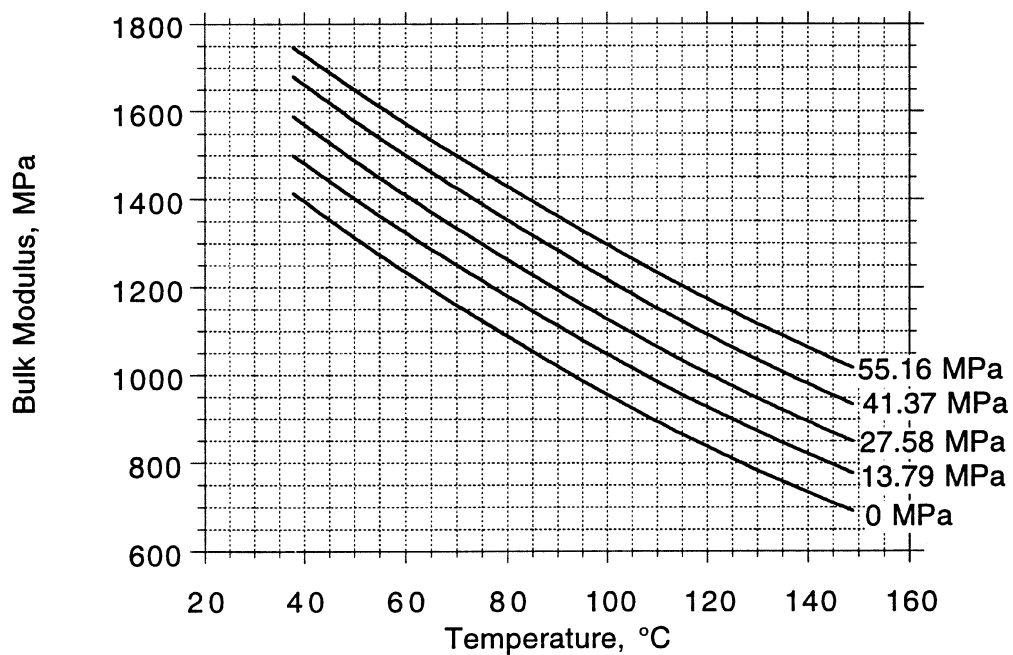


Figure 8B - Adiabatic secant bulk modulus of MIL-H-8446 (metric units)

Figure 8

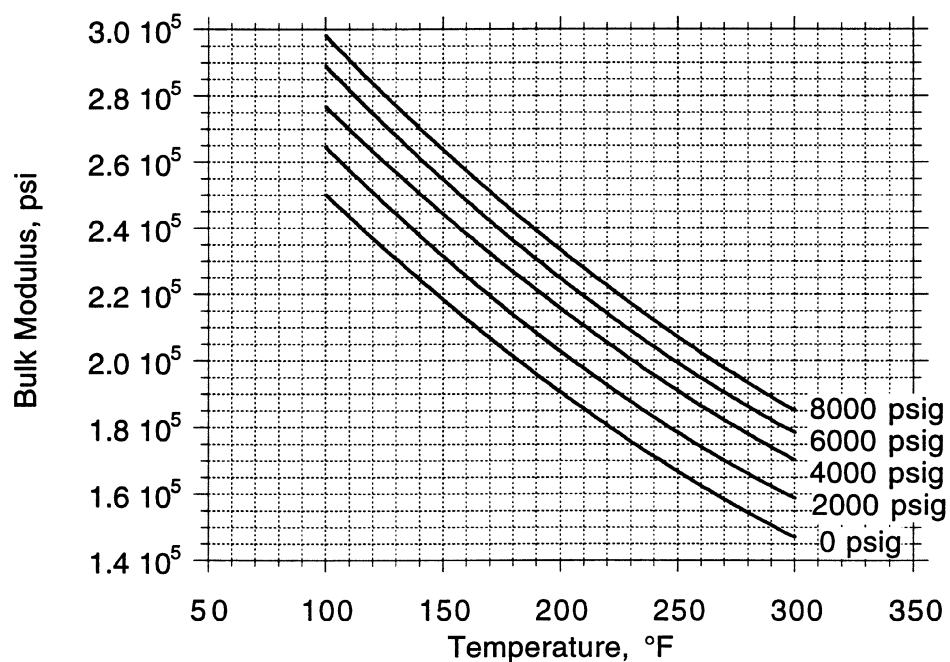


Figure 9A - Adiabatic secant bulk modulus of MIL-PRF-27601 (English units)

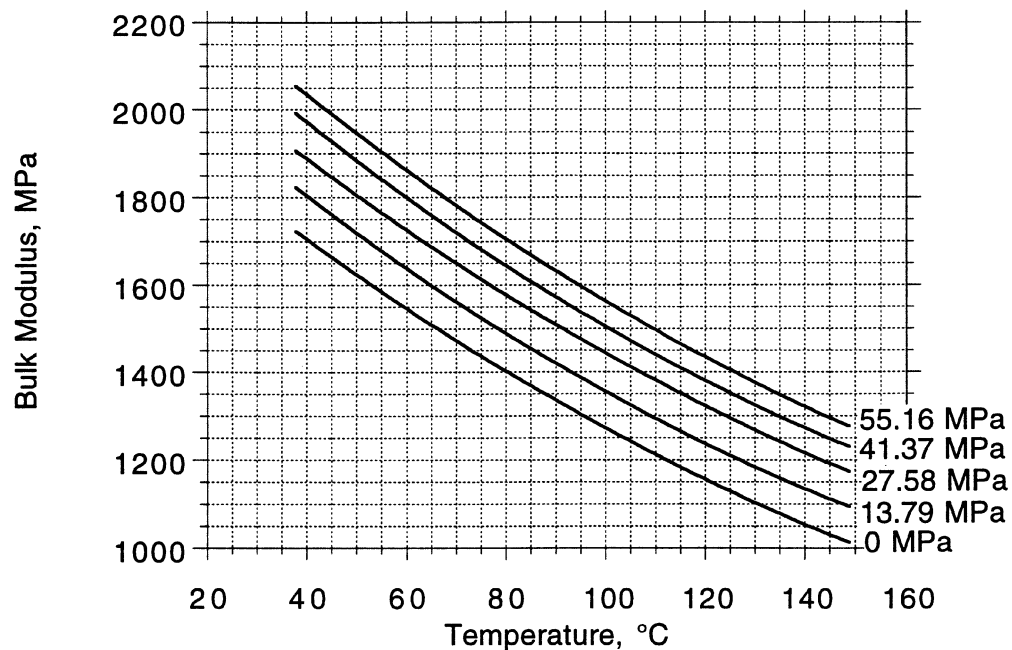


Figure 9B - Adiabatic secant bulk modulus of MIL-PRF-27601 (metric units)

Figure 9