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ROCKET DESIGN DATA HANDBOOK

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DIVISION OF BELL AEROSPACE CORPORATION – A textron COMPANY

ROCKET DESIGN DATA HANDBOOK

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BELL AEROSYSTEMS COMPANY
DIVISION OF BELL AEROSPACE CORPORATION—A textron COMPANY
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ROCKETS DEPARTMENT

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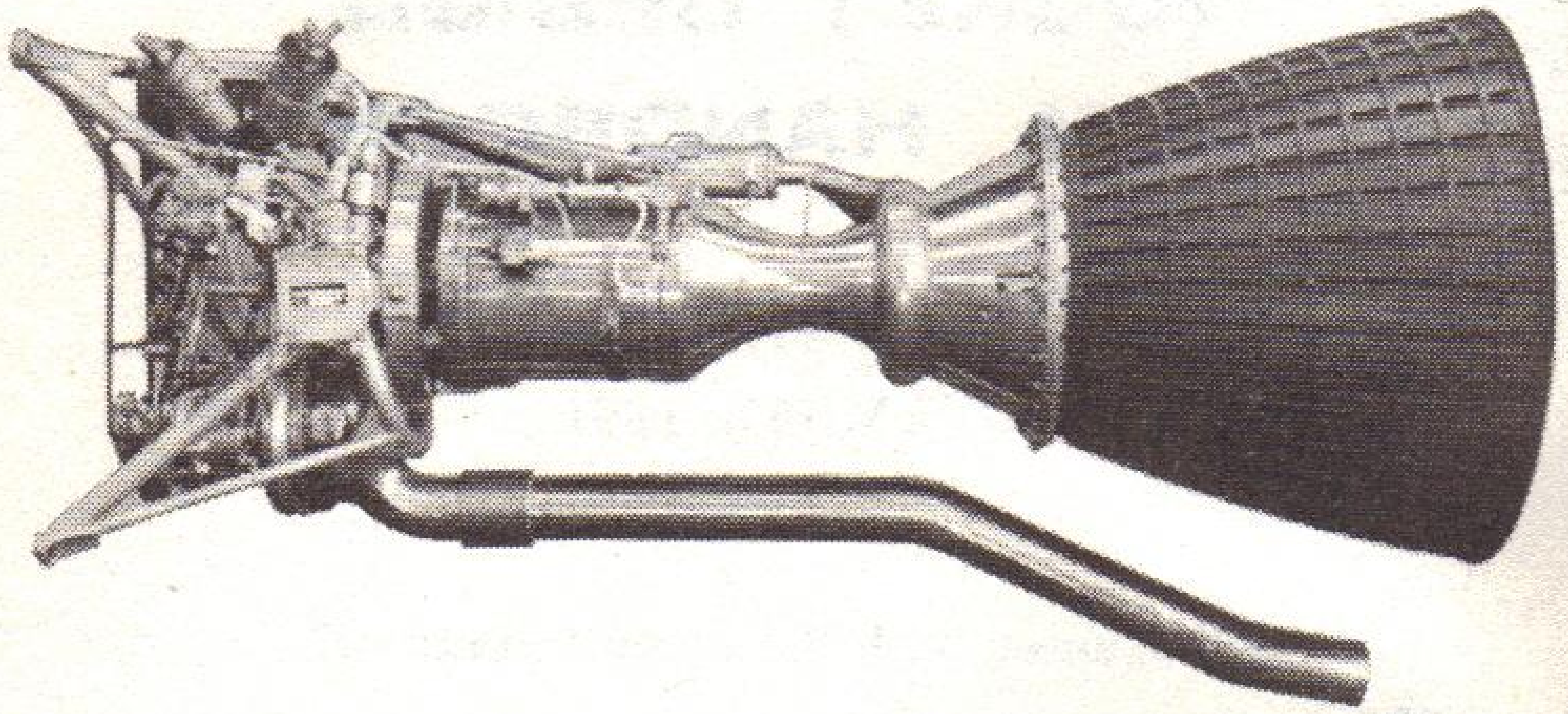
THE BELL AGENA ROCKET ENGINE



World's most reliable rocket engine — a record achieved by the Bell Agena Rocket Engine on the U.S. Air Force's DISCOVERER and MIDAS satellite programs*. Starting with DISCOVERER I on February 28, 1959, this rocket engine has performed as required in more than 35 space flights. The Bell Agena Rocket Engine is also scheduled for use on NASA's RANGER and MARINER spacecraft.

Thrust — 16,000 pounds
Engine Specific Impulse — Highest of any operational rocket engine in this class
Propellants — Red Fuming Nitric Acid and Unsymmetrical Dimethylhydrazine
Restart Capability — Two (2) engine starts in vacuum
Thrust Vector Control — Gimballed thrust chamber
Installation — Four point engine mount
Engine Weight — Approximately 290 pounds
Overall Length — Approximately 7 feet

*See Space Log pp. 84-88

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HIGHLIGHTS IN ROCKETRY

1232 A.D.	Battle of Kai-fung-fu. Assaults were repulsed by "arrows of flaming fire," consisting of ordinary arrows to which were tied small packages of incendiary powder.
1379	Battle for Isle of Chiozza. A defending tower was set afire by a crude powder rocket, eliminating last pocket of resistance.
1805	William Congreve of England (later knighted) demonstrated powder rockets with a range of 2000 yards.
1807	City of Copenhagen razed by a bombardment involving 25,000 rockets.
Aug. 24, 1814	Battle of Bladensburg. Employment of rockets defeated and dispersed troops, leading to capture of Washington, D. C.
Sept. 1814	Battle of Fort McHenry. Renowned primarily for its contribution to the "Star Spangled Banner."
1838	First patent granted (England) for life saving rocket subsequently employed by coastal rescue units.
1903	Konstantin Eduardovich Ziolkovsky (Russia) published first treatise on space travel advocating the use of liquid fuel rockets.

1919	Dr. Robert H. Goddard, the father of American rocketry, wrote "A Method of Reaching Extreme Altitudes." Two years later Dr. Goddard began experiments with liquid fuel rockets.
1923	Herman Oberth of Germany authored "The Rocket into Interplanetary Space." Oberth, like Dr. Goddard, favored liquid fuel rockets because of their greater combustion efficiency.
March 16, 1926	Dr. Goddard launched the first vehicle to be powered by a liquid-fuel rocket engine. The vehicle traveled a distance of 184 feet in 2.5 seconds.
1927	Foundation in Germany of Society for Space Travel (Verein fur Raumschiffahrt).
1928	Fritz Von Opel of Germany flew first rocket-propelled aircraft near Frankfurt (solid propellant charges mounted on a glider).
1930	Foundation of American Interplanetary Society. In 1934, the name of the organization was changed to American Rocket Society.
Dec. 30, 1930	Rocket flight conducted by Dr. Goddard attained an altitude of 4800 feet, a range of 13,000 feet, and a speed of 550 miles per hour.
May 31, 1935	Rocket flight conducted by Dr. Goddard attained an altitude of 7500 feet.
1937	Establishment of Research Institute at Peenemunde.

1938	Early model of German V-2 (A-3) attained an altitude of 40,000 feet and a range of 11 miles.
1942-1945	Solid propellant rockets employed by Armed Forces for artillery projectiles and aircraft assist take-off (JATO) applications.
1942	First flight of prototype V-2 (A-4).
April, 1942	First American military airplane to use liquid fuel rockets for assisted take-off.
July 5, 1944	First American aircraft (Northrop MX-324) powered by liquid fuel rocket engine.
Sept. 8, 1944	First V-2 attack on city of London.
December 1944	First American liquid rocket guided missile (Private A) launched.
Ocotober 1945	First flight of WAC Corporal attained an altitude of 43.5 miles.
Oct. 14, 1947	Bell Aircraft Corporation X-1, powered by a Reaction Motors, Incorporated (RMI) rocket engine, completed the first piloted supersonic flight in history.
Feb. 24, 1949	"Bumper" configuration consisting of V-2, on which was mounted a WAC Corporal, attained a record-breaking altitude of 250 miles.
Dec. 12, 1953	Bell Aircraft Corporation X-1A airplane, powered by RMI rocket engine, established a new unofficial world's speed record of over 1600 mph.

July 23, 1956	Bell Aircraft Corporation X-2 airplane, powered by Curtiss-Wright rocket engine established a new unofficial world's speed record of 1900 mph.
Sept. 7, 1956	Bell X-2 established new unofficial world's altitude record of over 126,200 feet.
Sept. 27, 1956	Bell X-2 established new unofficial world's speed record of 2148 mph.
Oct. 4, 1957	The U.S.S.R. launched "Sputnik I," the world's first satellite. Weighing an estimated 184 pounds, it orbited at an altitude of 170 to 580 miles.
Nov. 3, 1957	The U.S.S.R. launched "Sputnik II," the first satellite to contain a living animal.
Jan. 31, 1958	United States launched its first satellite, "Explorer I."
March 17, 1958	United States launched "Vanguard I."
Aug. 4, 1960	X-15 utilizing Bell Aerosystems Company reaction controls establishes new speed record of 2196 mph.
Aug. 12, 1960	X-15 establishes new altitude record at 136,500 feet.

SPACE LOG. See pages 84 to 86

ROCKET SYMBOLS

A_e	Nozzle exit area	in.^{2}
A_t	Throat area	in.^{2}
A_w	Chamber inner surface area	in.^{2}
C_f	Thrust coefficient	none
c*	Characteristic exhaust velocity	ft/sec
c	Effective exhaust velocity	ft/sec
F	Thrust	lb
g	Acceleration of gravity	ft/sec^2
h	Altitude	ft
I_{sp}	Specific impulse	sec
I_t	Total impulse	lb-sec
k	Ratio of specific heats C_p/C_v	none
L*	Characteristic length	in.
M	Molecular weight	lb/mol
$\dot{M}$	Mass flow, $\dot{W}/g$	lb-sec/ft
n	Polytropic exponent	none
P_c	Chamber pressure, absolute	lb/in.^{2}
P_e	Exit pressure, absolute	lb/in.^{2}
P_o	Ambient absolute pressure	lb/in.^{2}
r	Mixture ratio, $\dot{W}_o/\dot{W}_f$	none
R	Universal gas constant (1545)	ft-lb/mol-°R
T	Absolute temperature	°R
T_c	Combustion temperature	°R

t	Time	sec
v	Velocity	ft/sec
v_e	Exhaust velocity	ft/sec
v_s	Satellite velocity	ft/sec
V	Specific volume	ft^3/lb
V_c	Thrust chamber volume	$in.^3$
W	Weight	lb
W_f	Weight of fuel	lb
W_i	Initial weight	lb
W_o	Weight of oxidizer	lb
$\dot{W}$	Fluid flow rate	lb/sec
$\dot{W}_f$	Fuel flow rate	lb/sec
$\dot{W}_o$	Oxidizer flow rate	lb/sec
γ	Weight density	lb/ft^3
δ	Specific gravity	none
ϵ	Area ratio, A_e/A_t	none
η	Efficiency	none
ρ	Mass density	$lb\text{-}sec^2/ft^4$

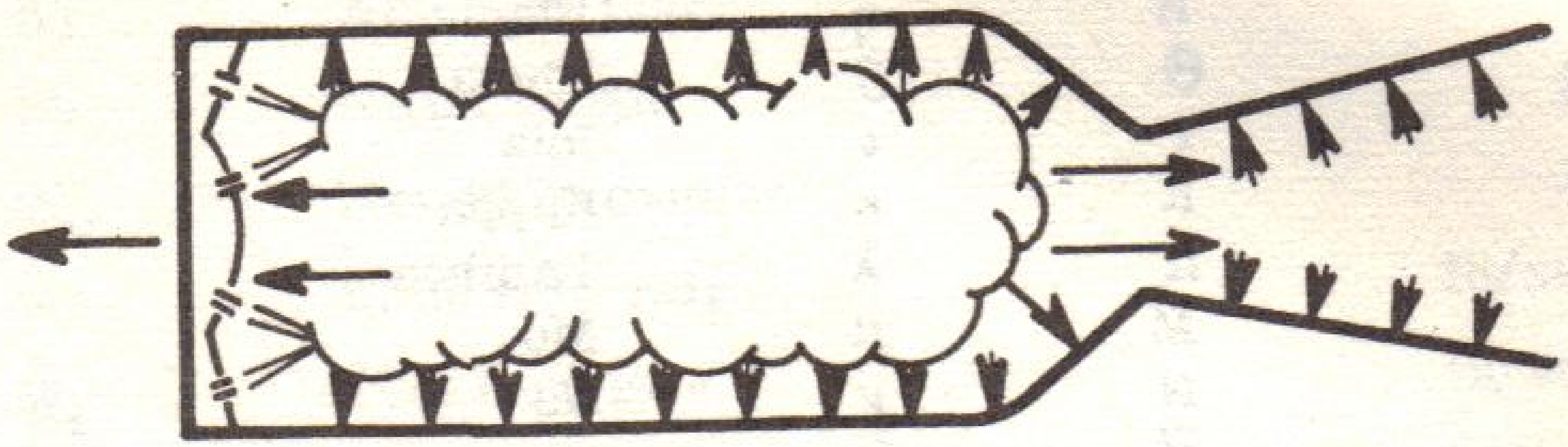
GREEK ALPHABET

Α	α	Alpha
Β	β	Beta
Γ	γ	Gamma
Δ	δ	Delta
Ε	ε	Epsilon
Ζ	ζ	Zeta
Η	η	Eta
Θ	θ	Theta
Ι	ι	Iota
Κ	κ	Kappa
Λ	λ	Lambda
Μ	μ	Mu
Ν	ν	Nu
Ξ	ξ	Xi
Ο	ο	Omicron
Π	π	Pi
Ρ	ρ	Rho
Σ	σ	Sigma
Τ	τ	Tau
Υ	υ	Upsilon
Φ	φ	Phi
Χ	χ	Chi
Ψ	ψ	Psi
Ω	ω	Omega

ROCKET RELATIONSHIPS

PRINCIPLES OF ROCKET PROPULSION

The fundamental principle upon which all jet and rocket prime movers operate is based on Newton's third law, i.e., for every action there is an equal and opposite reaction. To afford a more complete understanding, consider the following illustration of a typical rocket thrust chamber.



Upon combustion of the propellants in the thrust chamber, the gases expand through the nozzle at a high velocity. The internal pressure at the nozzle end is relieved, leaving an unbalanced pressure at the other end which tends to propel the chamber or the vehicle to which it is mounted in the direction opposite to the issuing jet. Propulsion is dependent upon internal conditions alone and not the effect of the jet pushing against the surrounding air.

The propulsive force exerted by the jet is expressed as

$$\text{Thrust} = \frac{\dot{W} v_e}{g} + A_e (P_e - P_o)$$

where $\dot{W}$ represents the propellant flow rate, v_e the nozzle exhaust velocity, A_e the nozzle exit area, P_e the exit pressure, and P_o atmospheric pressure. In a perfect vacuum, P_o is equal to zero, indicating that the thrust increases with altitude.

In contrast to other forms of jet engines, the rocket does not use the oxygen in the atmosphere for the combustion process. Instead, the oxidizer is carried aloft with the fuel. Thus, the rocket is the only means of achieving travel beyond the atmosphere of the earth.

ROCKET EQUATIONS

Thrust

$$F = \frac{\dot{W}}{g} v_e + (P_e - P_o) A_e$$

Effective Exhaust Velocity

$$c = \frac{Fg}{\dot{W}} = I_{sp}\, g = v_e + \frac{P_e - P_o}{\dot{W}} A_e\, g$$

Characteristic Velocity - Frozen Composition
(see page 17)

$$c^* = \frac{P_c A_t g}{\dot{W}} = \frac{I_{sp} g}{C_f} = \frac{\sqrt{gkR \dfrac{T_c}{M}}}{k\left(\dfrac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}}}$$

Coefficient of Thrust - Frozen Composition

$$C_f = \frac{F}{P_c A_t} = \sqrt{\frac{2k^2}{k-1}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]} + \frac{(P_e - P_o)}{P_c}\,\frac{A_e}{A_t}$$

Total Impulse

$$I_t = W_p I_{sp} = F \times t$$

W_p = total weight of propellants

Density Impulse

$$I_D = I_{sp}\ \delta_p$$

Propellant Bulk Specific Gravity

$$\delta_p = \frac{1+r}{\dfrac{1}{\delta_f} + \dfrac{r}{\delta_o}}$$

δ_f = specific gravity of fuel, δ_o = specific gravity of oxidizer

Characteristic Length

$$L^* = \frac{V_c}{A_t}$$

Stay Time of Combustion Gases in Chamber

$$t_c = \frac{V_c}{\dot{W}} \times \frac{P_c}{12R\left(\dfrac{T_c}{M}\right)}$$

Mach Number

$$Ma = \frac{v}{a} = \frac{v}{\sqrt{kgR'T}}$$

a = speed of sound, ft/sec

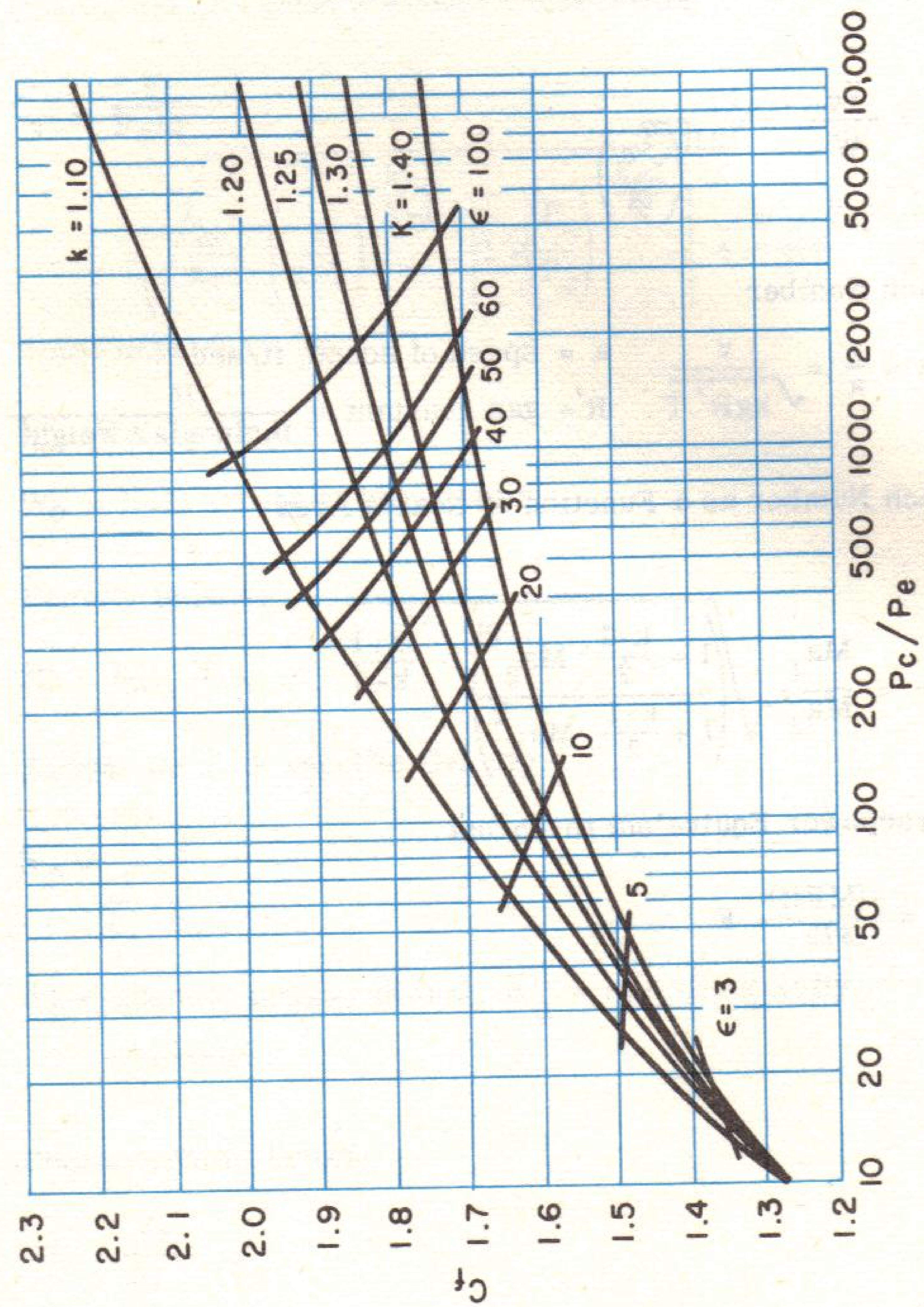
R' = gas constant = $\dfrac{R}{\text{molecular weight}}$

Mach Number as a Function of Nozzle Area

$$\frac{A_2}{A_1} = \frac{Ma_1}{Ma_2}\sqrt{\left(\frac{1+\frac{k-1}{2}Ma_2^{\,2}}{1+\frac{k-1}{2}Ma_1^{\,2}}\right)^{\frac{k+1}{k-1}}}$$

Horsepower Equivalent to Thrust

$$HP = \frac{v(MPH)}{375}\,F$$

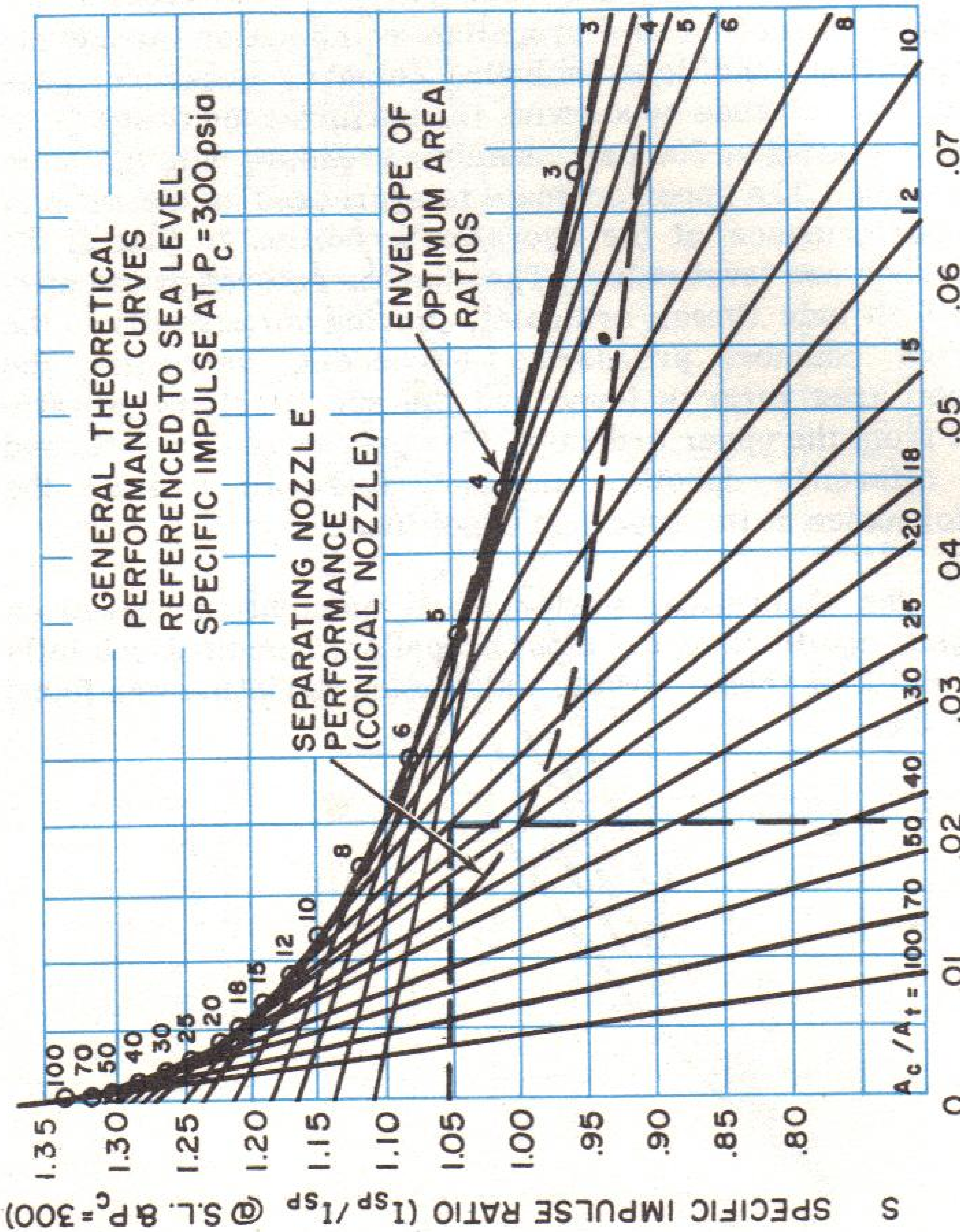


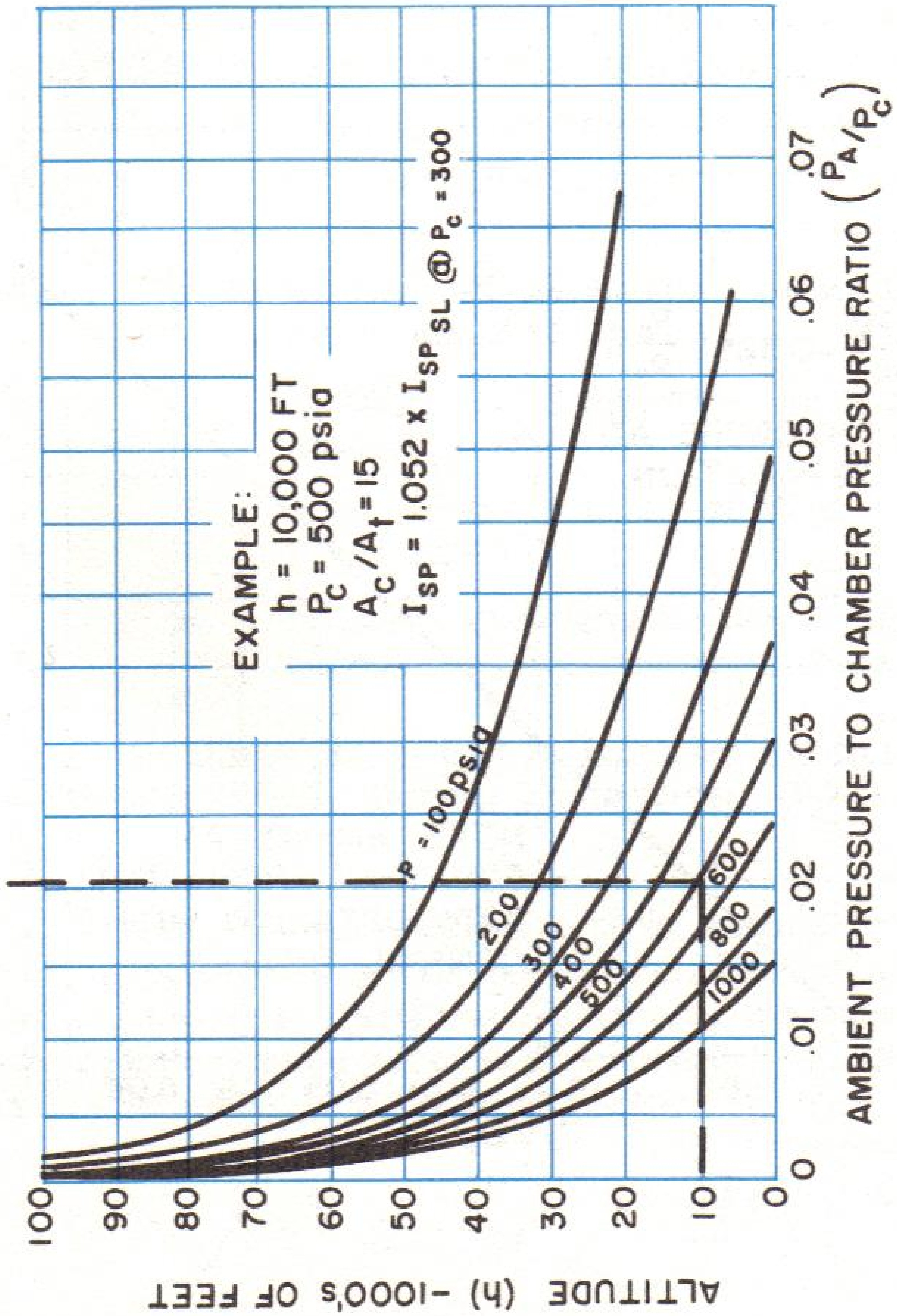
Thrust Coefficient, C_f, as a Function of Pressure Ratio, Area Ratio, and Specific Heat Ratio for Optimum Expansion Conditions

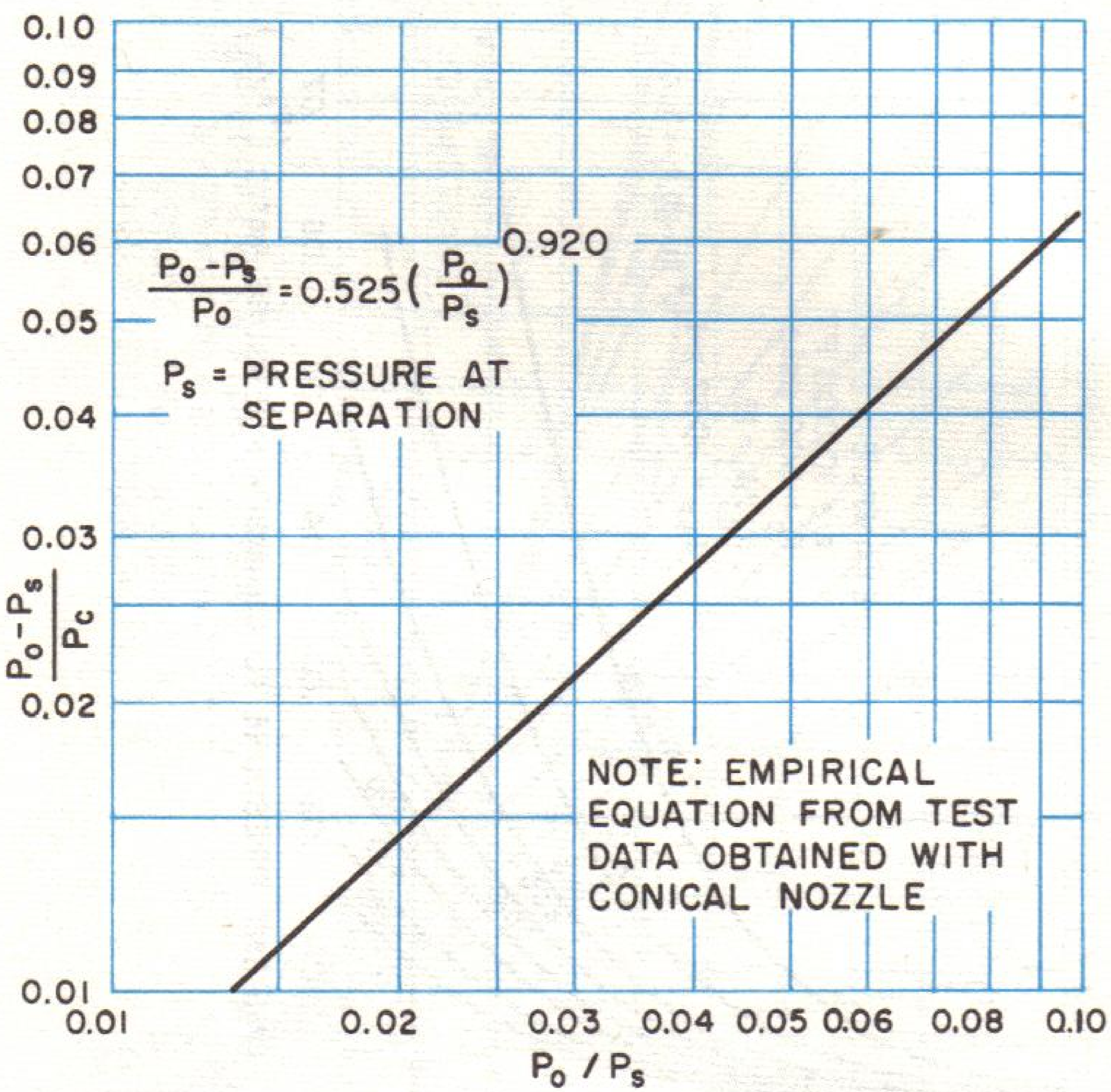
General Theoretical Thrust Chamber Performance

The plot on pages 14 and 15 is designed to estimate the performance of any propellant combination for any set of operating conditions including chamber pressure, area ratio, and altitude by knowing the performance at sea level when operating at 300 psia chamber pressure with optimum expansion. The upper ordinate is expressed as the ratio of the performance at the operating condition to that at the reference sea level value. The chart is entered at the specified altitude (lower ordinate), moving horizontally to the correct chamber pressure. Proceeding vertically, the chosen area ratio is found and the specific impulse ratio read from the upper ordinate. The product of this ratio and the reference specific impulse value will indicate the performance at the specified conditions.

The theoretical performance calculations based on shifting equilibrium for most propellant combinations falls within 1% of these curves. Maximum deviation was found to be 3%.


GENERAL THEORETICAL PERFORMANCE CURVES REFERENCED TO SEA LEVEL SPECIFIC IMPULSE AT P_C = 300 psia
ENVELOPE OF OPTIMUM AREA RATIOS
SEPARATING NOZZLE PERFORMANCE (CONICAL NOZZLE)
A_c/A_t = 100 70 50 40 30 25 20 18 15 12 10 8 6 5 4 3
0 .01 .02 .03 .04 .05 .06 .07
AMBIENT PRESSURE TO CHAMBER PRESSURE RATIO (P_A/P_C)
1.35 1.30 1.25 1.20 1.15 1.10 1.05 1.00 .95 .90 .85 .80
S SPECIFIC IMPULSE RATIO (I_{SP}/I_{SP} @ S.L. & P_c=300)


EXAMPLE:
h = 10,000 FT
P_C = 500 psia
A_C/A_t = 15
I_{SP} = 1.052 x $I_{SP\ SL}$ @ P_c = 300
P = 100 psia
200 300 400 500 600 800 1000
0 .01 .02 .03 .04 .05 .06 .07
AMBIENT PRESSURE TO CHAMBER PRESSURE RATIO (P_A/P_C)
100 90 80 70 60 50 40 30 20 10 0
ALTITUDE (h) -1000's OF FEET



PERFORMANCE OF ROCKET PROPELLANTS

The specific impulse (I_{sp}) of a propellant combination is related to the energy content of the combustion gases. The general equation for specific impulse is:

$$I_{sp} = \sqrt{\frac{2J}{g} \left(h_c - h_e\right)_s}$$

where

h_c = enthalpy of combustion products before expansion, BTU/lb

h_e = enthalpy of combustion products after expansion, BTU/lb

J = mechanical equivalent of heat = 778 ft-lb/BTU

s = denotes expansion at constant entropy, with chemical equilibrium maintained

Calculations performed in accordance with the above equation are called "Shifting Equilibrium" (S.E.) calculations.

If it is assumed that there is no shifting equilibrium during expansion, and that the specific heat of the gas is constant, ideal gas relationships can be substituted in the above equation, and a "Frozen Composition" (F.C.) calculation can be made. The modified equation is:

$$I_{sp} = \sqrt{\frac{2R}{g} \; \frac{k}{k-1} \; \frac{T_c}{M} \left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}$$

The above relations are for a fully expanded exhaust nozzle (i.e. $P_e = P_o$).

LIQUID BIPROPELLANT COMBINATIONS

Oxidizer	Fuel	r	T_c(°F)	I_{sp} 300→14.7 psia		Bulk Sp. Gr.
Chlorine Trifluoride:	Ammonia*	3.93	4980	240	(F.C.)	1.34
	Hydrazine*	2.5	6100	258	(S.E.)	1.45
	Methyl Alcohol*	2.88	5150	230	(S.E.)	1.35
Liquid Fluorine:	Ammonia*	3.00	7280	311	(S.E.)	1.158
	Hydrazine*	2.00	7324	315	(S.E.)	1.293
	Hydrogen*	5.67	5514	364	(S.E.)	0.376
	Lithium*	2.19	7000	336	(S.E.)	0.960
	Methyl Alcohol*	2.375	7182	299	(S.E.)	1.193
90% Hydrogen Peroxide:	JP-4	7.75	4508	234.5	(S.E.)	1.26
	uns-Dimethyl-hydrazine*	4.40	4490	239.5	(S.E.)	1.21
	Hydrazine*	2.04	4350	242.6	(S.E.)	1.235
Mixed Oxides of Nitrogen (24% NO):	uns-Dimethyl-hydrazine*	2.5	5642	255	(S.E.)	1.17
Nitrogen Tetroxide:	Ammonia	2.029	4627	238	(S.E.)	1.07
	Aniline*	3.87	5742	221	(F.C.)	1.36
	Benzene	4.418	5598	214	(F.C.)	1.32
	Ethylamine*	4.096	5538	230	(F.C.)	1.22
	Hydrazine*	1.25	5080	254.5	(S.E.)	1.23
	Hydrogen	11.5	5610	279	(F.C.)	0.57
	Isopropyl Alcohol	3.06	4773	224	(F.C.)	1.22
	Propane	4.15	5121	240	(F.C.)	1.15
	Turpentine (α pinene)*	4.7	5542	221	(F.C.)	1.35
	UDMH	2.25	5288	249.5	(S.E.)	1.143
	Xylidene*	3.00	5470	223	(F.C.)	1.32
Nitrogen Trifluoride:	Ammonia	4.2	6128	277	(S.E.)	1.24
Liquid Oxygen:	Acetylene	1.23	6012	266	(F.C.)	0.83
	Aluminum Borohydride	1.32	6000	276	(F.C.)	0.775
	Ammonia	1.25	4834	250	(F.C.)	0.878
	Ethyl Alcohol	1.50	5297	242	(F.C.)	0.969
	Ethylene	1.86	5538	264	(F.C.)	0.842
	Hydrazine	0.83	5382	263	(F.C.)	1.062
	Hydrazine Hydrate	1.00	4572	242	(F.C.)	1.07
	Hydrogen	3.5	4426	347	(S.C.)	0.262
	Isopropyl Alcohol	1.85	5553	241	(F.C.)	0.982
	Lithium	1.15	13000	318	(F.C.)	0.746
	JP-4	2.4	5737	263	(S.E.)	1.005
	Lithium Borohydride*	1.47	8300	306	(F.C.)	—

NOTE: *Denotes that the propellant combination is hypergolic, i.e., the propellants burn spontaneously upon mixing.

Oxidizer	Fuel	r	T_c(°F)	I_{sp} 300→14.7 psia		Bulk Sp. Gr.
	Lithium Hydride*	1.34	6400	268	(F.C.)	0.98
	Methane	2.33	4874	263	(F.C.)	0.71
	Methyl Alcohol	1.15	5076	237	(F.C.)	0.950
	Methyl Amine	2.06	5600	252	(F.C.)	0.986
	Nitromethane	0.076	4703	226	(F.C.)	1.13
	n-Octane	2.33	5625	262	(S.E.)	0.962
Oxygen Difluoride:	Ammonia	2.08	6042	292	(S.E.)	1.08
	Hydrazine	1.35	6285	299	(S.E.)	1.24
Ozone:	Ammonia	1.13	5175	267	(F.C.)	0.974
	Hydrazine	0.63	5418	277	(F.C.)	1.167
	Hydrogen	3.5	5026	375	(S.E.)	0.275
	JP-4	2.2	6327	286	(S.E.)	1.193
Perchloryl-fluoride:	Hydrazine*	1.30	5516	262	(S.E.)	1.30
	JP-4	3.85	6092	249	(S.E.)	1.34
	uns-Dimethyl-hydrazine	2.45		254.5	(S.E.)	1.27
RFNA (14% NO_2):	Ammonia	2.20	4202	231.5	(S.E.)	1.11
	Diethylenetriamine*	3.61	4908	234	(S.E.)	1.37
	Hydrazine*	1.40	4796	246	(S.E.)	1.267
	JP-4	4.65	5012	231.5	(S.E.)	1.31
	Turpentine (α pinene)*	4.4	5113	231	(S.E.)	1.353
	Toluene	4.1	5130	227	(S.E.)	1.345
	uns-Dimethyl-hydrazine	2.7	4920	239	(S.E.)	1.23
WFNA:	Aniline*	3.00	4942	222	(F.C.)	1.346
	Furfuryl Alcohol*	2.65	4885	210	(F.C.)	1.382
	Hydrazine*	1.22	4681	246	(S.E.)	1.228
	Hydrogen	12.6	5360	298	(F.C.)	0.604
	JP-4	4.65	5032	230	(S.E.)	1.29
	Methyl Alcohol	2.36	4480	219	(F.C.)	1.190
	Methyl-Furfuryl Alcohols (50-50)*	2.52	4699	213	(F.C.)	1.30
	n-Octane	4.00	4744	229	(F.C.)	1.226

NOTE: *Denotes that the propellant combination is hypergolic, i.e., the propellants burn spontaneously upon mixing.

PERFORMANCE OF MONOPROPELLANTS

Name	Formula	T_c (°F)	I_{sp} 300→14.7 psia	Sp. Gr.
Ethylene Oxide	C_2H_4O	2114	166(F.C.)	0.887
Hydrazine	N_2H_4	1125	174(S.E.)	1.0045
Nitromethane	CH_3NO_2	3950	218(F.C.)	1.13
n-Propyl Nitrate	$CH_3CH_2CH_2NO_3$	1886	179(S.E.)	0.935
90% Hydrogen Peroxide	H_2O_2	1381	133(S.E.)	1.387

PHYSICAL PROPERTIES OF FUELS

Name	Formula	B.P. (°F)	F.P. (°F)	Approx. Cost $/lb (1957)	Specific Gravity** (Temp. °F)
Acetylene	C_2H_2	-119 subl.	-115	0.15	0.62 (-119.2)
Aluminum Borohydride	$Al(BH_4)_3$	113	-85		0.544
Ammonia	NH_3	-28	-108	0.043	0.682 (-28)
Aniline	$C_6H_5NH_2$	364	21	0.23	1.022
Benzene	C_6H_6	176	42	0.05	0.879
Diethylenetriamine	$(NH_2C_2H_4)_2NH$	404.8	-38.2	0.415-0.43	0.954
Ethyl Alcohol	C_2H_5OH	174	-175	0.06	0.790
Ethyl Alcohol 75% Water 25%	$C_2H_5OH+H_2O$	179	-76	0.05	0.854
Ethylamine	$C_2H_5NH_2$	63	-114	0.30	0.706
Ethylene	C_2H_4	-155	-273	0.75	0.566 (-152)
Ethylene Oxide*	C_2H_4O	52	-168	0.245	0.887 (45)
Ethyl Nitrate*	$C_2H_5NO_3$	192	-152	2.00	1.105

* Can be used as a monopropellant
** At 60°F unless otherwise noted

Name	Formula	B.P. (°F)	F.P. (°F)	Approx. Cost $/lb	Specific Gravity** (Temp. °F)
Furfuryl Alcohol	$C_4H_3OCH_2OH$	340	-26	0.21	1.138
Heptane	C_7H_{16}	208	-131	0.32	0.684
Hydrazine	N_2H_4	236	35	3.00	1.00
68% Hydrazine	$N_2H_4+H_2O$	250	-63	1.75	1.00
Hydrogen	H_2	-422	-434	0.70 gas 10.00 liq.	0.0708 (-423)
Isopropyl Alcohol	C_3H_7OH	180	-128	0.10	0.781
JP-4 (MIL-F-5642B)	Hydrocarbon Mixture	470 (90%)	-76	0.017	0.751-0.802
JP-5 (MIL-F-5624B)	Hydrocarbon Mixture	550 (e.p.)	-40	0.02	0.80-0.85
Lithium	Li	2507	367	13.00-20.00	0.534
Lithium Hydride	Li H	--	1256	--	0.82
Methane	CH_4	-258	-296	0.15	0.38 (-164)
Methyl Alcohol	CH_3OH	150	-144	0.05	0.796
Methylamine	CH_3NH_2	20	-135	0.31	0.769
Nitromethane*	CH_3NO_2	214	-19	0.25	1.13
n-Octane	C_8H_{18}	257	-71	0.10	0.704
Propane	C_3H_8	-44	-310	0.004	0.585 (-48)
n-Propyl Nitrate*	$C_3H_7NO_3$	230	-150	0.40	0.935
RP-1	Hydrocarbon Mixture	500 (90%)	-76	0.02	0.801-0.815
Toluene	$C_6H_5CH_3$	231	-139	0.04	0.862
Triethylaluminum	$(C_2H_5)_3Al$	367	-53	20.00	0.835
Triethylamine	$N(C_2H_5)_3$	192	-175	0.47	0.728
Turpentine (α pinene)*	$C_{10}H_{16}$	309	-67	0.12	0.858
uns-Dimethylhydrazine	$N_2H_2(CH_3)_2$	146	-71	2.40-3.25	0.785
2, 3-Xylidene	$(CH_3)_2C_6H_3NH_2$	428	-58	0.50	0.98

* Can be used as a monopropellant.
** At 60°F unless otherwise noted.

PHYSICAL PROPERTIES OF OXIDIZERS

Name	Formula	B. P. (°F)	F. P. (°F)	Approx. Cost $/lb	Specific Gravity (Temp. °F)**
Chlorine Trifluoride	ClF_3	52.2	-105.3	3.00	1.83
Fluorine	F_2	-306	-363	4.00-10.00	1.51 (-306)
Hydrogen Peroxide*	H_2O_2	288	31	1.00	1.392
90% Hydrogen Peroxide*	$H_2O_2+H_2O$	285	11.3	0.53-0.61	1.387
Mixed Oxides of Nitrogen	76% N_2O_4 24% NO			0.10	1.46 (26)
Nitric Acid:					
WFNA (MIL-N-7254C)	HNO_3	187	-43	0.056	1.505
RFNA (14.0% NO_2) (MIL-N-7254C)	$HNO_3+NO_2+H_2O$	142	-65	0.055	1.558
Nitrogen Tetroxide	N_2O_4	70	12	0.075	1.49
Nitrogen Trifluoride	NF_3	-200	-341		1.54 (-200)
Oxygen	O_2	-297	-361	0.03-0.06	1.142 (-297)
Oxygen difluoride	OF_2	-228.6	-370.8		1.496 (-288.6)
Ozone	O_3	-169	-315		1.571 (-297)
Perchloryl Fluoride	ClO_3F	-52.2	-231	15.00	1.69 (-52.2)

* Can be used as a monopropellant.
** At 60°F unless otherwise noted.

ROCKET HEAT TRANSFER

Symbols		Dimensions
A	Cross section area of flow passage	ft^2
C_p	Specific heat at constant pressure	BTU/lb°F
D	Diameter	ft
D_h	Hydraulic diameter of coolant passage	ft
h_g	Gas coefficient of heat transfer	$BTU/ft^2sec°F$
h_L	Liquid coefficient of heat transfer	$BTU/ft^2sec°F$
k	Thermal conductivity	$BTU/ft^2sec°F/ft$
k_g	Gas thermal conductivity	$BTU/ft^2sec°F/ft$
k_w	Wall thermal conductivity	$BTU/ft^2sec°F/ft$
k_L	Liquid thermal conductivity	$BTU/ft^2sec°F/ft$
Pr	Prandtl number ($\mu C_p/k$)	none
q	Heat transfer rate	BTU/sec
q/a	Heat transfer flux	BTU/ft^2sec
Re	Reynolds number ($vD\gamma/\mu$)	none
t	Wall thickness	ft
T_b	Coolant bulk temperature	°R
T_c	Combustion temperature	°R
T_i	Wall inside surface temperature	°R
T_o	Wall outside surface temperature	°R
α	Wall absorptivity	none
ϵ	Gas emissivity	none
μ	Viscosity, absolute	lb/ft sec

Heat is transferred from the combustion gases to the chamber wall by forced convection and radiation. In a regeneratively cooled rocket, this heat is conducted through the wall and transferred by forced convection to the coolant (one of the propellants). The coolant must have sufficient heat capacity to absorb all of the incident heat without reaching its boiling point.

Heat Flux to Walls

Forced Convection

$$\left(\frac{q}{a}\right)_c = h_g \left(T_c - T_i\right)$$

where $h_g = 0.023 \frac{\dot{W}}{A} C_p \quad (Re)^{-0.2} \quad (Pr)^{-0.6}$

Radiation

$$\left(\frac{q}{a}\right)_r = 0.483\ \epsilon \cdot \alpha \left[\left(\frac{T_c}{1000}\right)^4 - \left(\frac{T_i}{1000}\right)^4\right]$$

Heat Conducted Through Walls

$$\frac{q}{a} = \left(\frac{q}{a}\right)_c + \left(\frac{q}{a}\right)_r$$

$$= \frac{k_w}{t}\left(T_i - T_o\right)$$

Heat Transferred to Coolant

$$\frac{q}{a} = h_L \left(T_o - T_b\right)$$

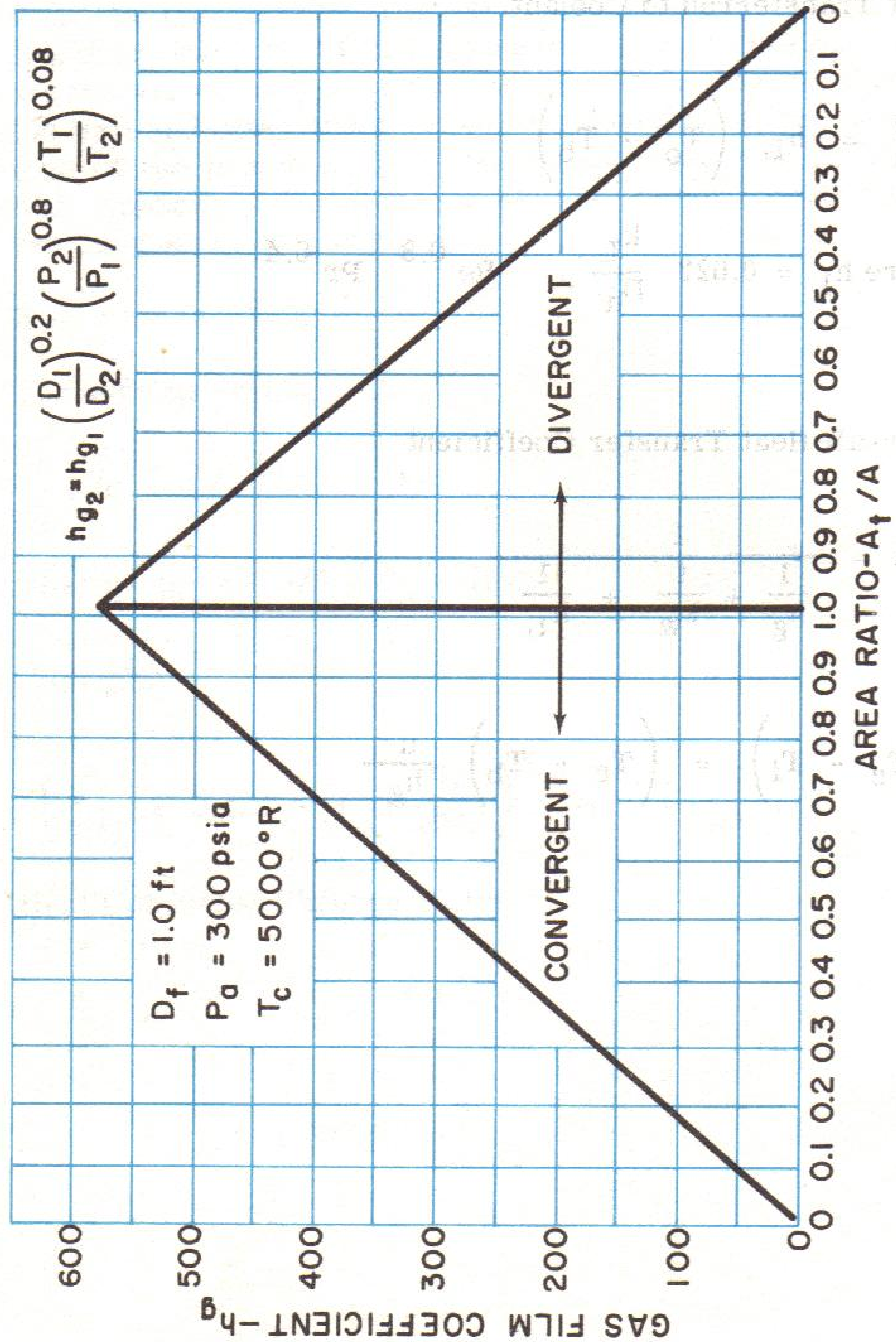
where $h_L = 0.023 \frac{k_L}{D_h} \cdot \quad Re^{0.8} \quad Pr^{0.4}$

Over-all Heat Transfer Coefficient

$$u = \frac{1}{\frac{1}{h_g} + \frac{t}{k_w} + \frac{1}{h_L}}$$

and

$$\left(T_c - T_i\right) = \left(T_c - T_b\right) \frac{u}{h_g}$$



Gas Film Coefficient vs. Area Ratio for Typical Rocket

PUMP RELATIONSHIPS

Symbols		Dimensions
b.hp.	Brake horsepower	hp
D	Impeller diameter	in.
f.hp.	Fluid horsepower	hp
H_f	Friction head	ft
H_p	Fluid static head	ft
H_{sv}	Suction head above vapor pressure	ft
H_t	Fluid total head	ft
H_v	Fluid velocity head	ft
H_{vp}	Fluid vapor pressure head	ft
H_z	Height of fluid surface above or below pump impeller centerline	ft
n	Rotational speed	rpm
n_s	Pump specific speed	$\frac{\text{rpm}\sqrt{\text{gpm}}}{\text{ft}^{3/4}}$
Q	Volume flow rate	gpm
S	Suction specific speed	$\frac{\text{rpm}\sqrt{\text{gpm}}}{\text{ft}^{3/4}}$
V	Fluid velocity	ft/sec
γ	Fluid specific weight	lb/cu ft
δ	Fluid specific gravity	none
η	Over-all efficiency	percent
Φ	Over-all head rise coefficient at point of maximum efficiency	none

Pump Specific Speed $n_s = n \dfrac{\sqrt{Q}}{H^{3/4}}$

Fluid Velocity Head $H_v = \dfrac{V^2}{2g}$

Fluid Total Head $H_t = H_p + H_v$

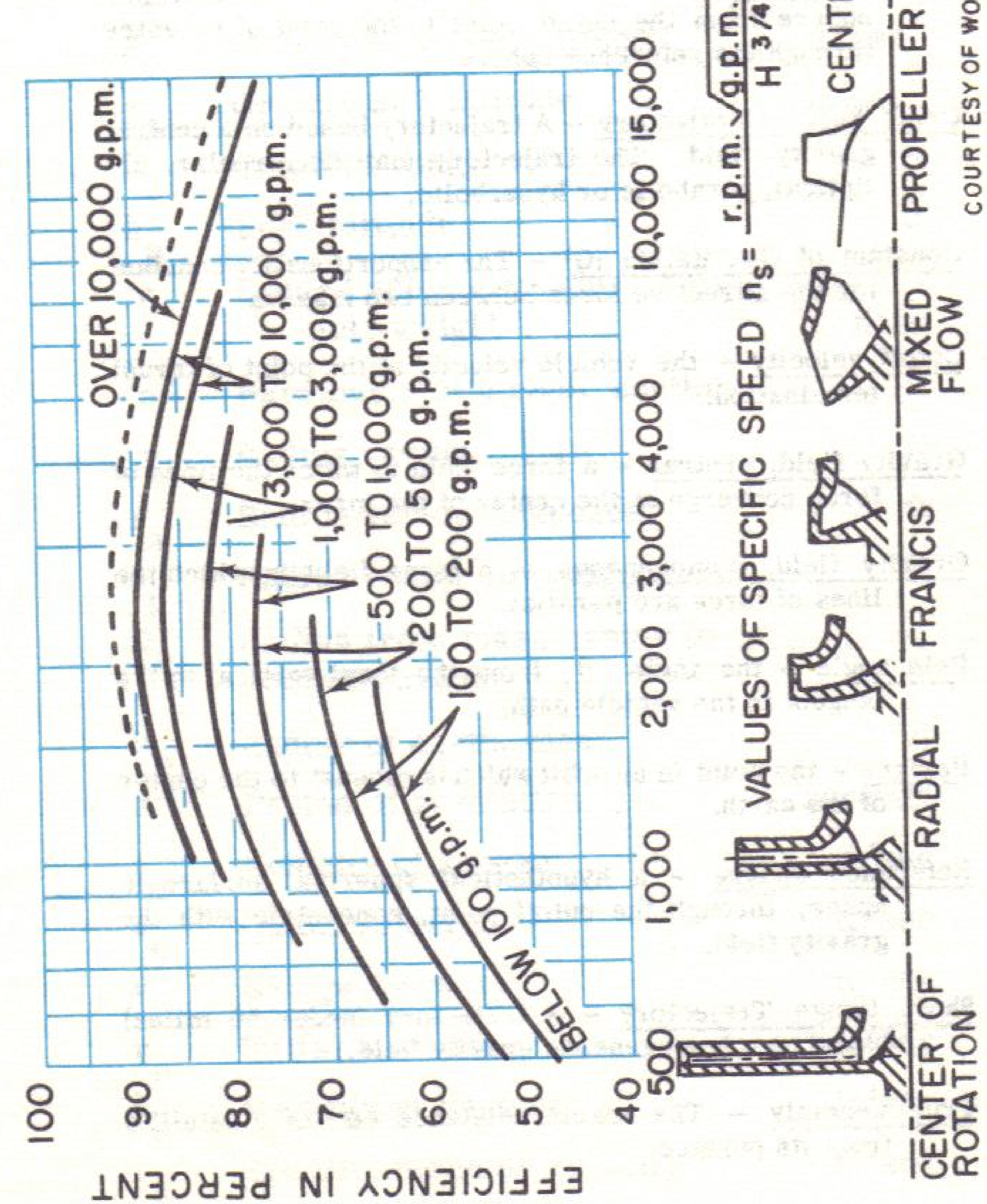
Section Head Above Vapor Pressure $H_{sv} = H_p + H_v = H_{vp}$

Suction Specific Speed $S = \dfrac{n\sqrt{Q}}{H_{sv}^{3/4}}$

Over-all Efficiency $\eta = \dfrac{\text{f. hp.}}{\text{b. hp.}}$

Fluid Horsepower $\text{f.hp.} = \dfrac{QH\,\delta}{3960}$

Impeller Diameter $D = \dfrac{1840\,\Phi\,\sqrt{H}}{n}$



Approximate Relative Impeller Shapes and Efficiencies as Related to Specific Speed

BALLISTIC AND CELESTIAL MECHANICS

Definitions

Apogee – the point in an elliptical orbit which is farthest from the center of the earth.

Ballistic range – the range on surface of the reference sphere from the cutoff point to the point of re-entry through the reference sphere.

Conic Section Trajectory – A trajectory based on a central gravity field. The trajectory may be circular, elliptical, parabolic or hyperbolic.

Constant of Gravitation (G) – The proportionality constant for the attractive force between two masses.

Cutoff velocity – the vehicle velocity at the point of thrust termination.

Gravity field, central – a force field in which the lines of force converge at the center of the mass.

Gravity field, homogeneous – a force field in which the lines of force are parallel.

Path angle – the angle (θ) from the local vertical to the tangent to the vehicle path.

Perigee – the point in an orbit which is closest to the center of the earth.

Reference sphere – a hypothetical spherical surface in space, through the cutoff point, concentric with the gravity field.

Short Range Trajectory – A trajectory (under 50 miles) based on a homogeneous gravity field.

True anomaly – The angular distance (α) of a satellite from its perigee.

Symbols		Dimensions
a	Semi-major axis of ellipse	ft
b	Semi-minor axis of ellipse	ft
e	Eccentricity of ellipse	none
g_e	Gravity at earth surface	ft/sec^2
g_c	Gravity at cutoff altitude	ft/sec^2
g_h	Gravity at h altitude	ft/sec^2
h_c	Cutoff altitude	ft
h_p	Peak altitude	ft
n	Loaded vehicle weight/cutoff vehicle weight	none
p	Parameter of a conic section	ft
r	Radius vector	ft
r_a	Radius vector to apogee	ft
r_p	Radius vector to perigee	ft
R_c	Radius from mass center to cutoff altitude	ft
R_e	Radius of earth, mean	ft
t	Period of revolution	seconds
v_a	Velocity at apogee	ft/sec
v_c	Cutoff velocity	ft/sec
v_e	Escape velocity	ft/sec
v_o	Initial velocity	ft/sec
v_p	Velocity at perigee	ft/sec
v_s	Satellite circular velocity	ft/sec

X	Range	ft
α	True anomaly (angle between major axis and radius vector)	degrees
θ	Path angle with vertical	degrees
θ_c	Cutoff path angle with vertical	degrees
μ	Gravitational factor, $g_c R_c^2$	ft^3/sec^2
ϕ	Launch angle with horizontal ($90^\circ - \theta$)	degrees
ψ	Initial thrust/weight ratio, F/W_i	none

SHORT RANGE BALLISTIC TRAJECTORIES

Range

$$X = \frac{v_c^2}{g} \sin 2\phi$$

Maximum Altitude

$$h = \frac{v_c^2}{2g} \sin^2\phi$$

Flight Duration

$$t = \frac{2v_c}{g} \sin \phi$$

SIMPLIFIED VERTICAL TRAJECTORY EQUATIONS

Assuming constant gravitational acceleration, constant thrust, and no drag

I_{sp} = mean effective specific impulse

$\psi = \frac{F}{W_i}$ = initial thrust to weight ratio

$$n = \frac{\text{loaded weight } (W_i)}{\text{cutoff weight } (W_c)}$$

Velocity at Cutoff (end of burning time)

$$v_c = g_e \; I_{sp} \left(\ln n - \frac{n-1}{\psi \, n}\right)$$

Altitude at Cutoff

$$h_c = g_e \left(I_{sp}\right)^2 \left(\frac{n-1}{\psi \, n}\right) \left[1 - \frac{\ln n}{n-1} - \frac{1}{2} \; \frac{n-1}{\psi \, n}\right]$$

Height from Cutoff to Peak Altitude

$$h_{p-c} = \frac{g_e^2}{2\bar{g}} \left(I_{sp}\right)^2 \left(\ln n - \frac{n-1}{\psi \, n}\right)^2$$

$\bar{g}$ = average gravity from cutoff to peak altitude

Peak Altitude

$$h_p = h_c + h_{p-c}$$

Time of Powered Flight $t = \frac{n-1}{\psi \, n} I_{sp}$

MECHANICS OF CONIC SECTION TRAJECTORIES

Escape Velocity, Minimum

$$v_e = R_e\sqrt{\frac{2g_e}{R_e + h}} = v_s\sqrt{2}$$

Satellite Circular Velocity

$$v_s = R_e\sqrt{\frac{g_e}{R_e + h}}$$

Variation of Gravity with Altitude

$$g_h = g_e\left(\frac{R_e}{R_e + h}\right)^2$$

Parameter of a Conic Section Trajectory

$$p = \frac{b^2}{a} = \frac{v_c^2 \sin \theta_c}{g_c}$$

Eccentricity of a Conic Section Trajectory

$$e = \sqrt{\frac{a^2 - b^2}{a}} = \sqrt{1 + \frac{\left(v_c^2 - \frac{2\mu}{R_e}\right) v_c^2 R_c^2 \sin^2 \theta_c}{\mu^2}}$$

Satellite Velocity in an Elliptical Orbit

$$v_a = \sqrt{\frac{\mu(1-e)}{r_a}} = \sqrt{\frac{\mu(1-e)}{a(1+e)}}$$

$$v_p = \sqrt{\frac{\mu(1+e)}{r_p}} = \sqrt{\frac{\mu(1+e)}{a(1-e)}}$$

Period of Revolution of a Circular Orbit Relative to Earth

$$t = \frac{2\pi(R_e + h)}{v_s}$$

Period of Revolution of an Elliptical Orbit

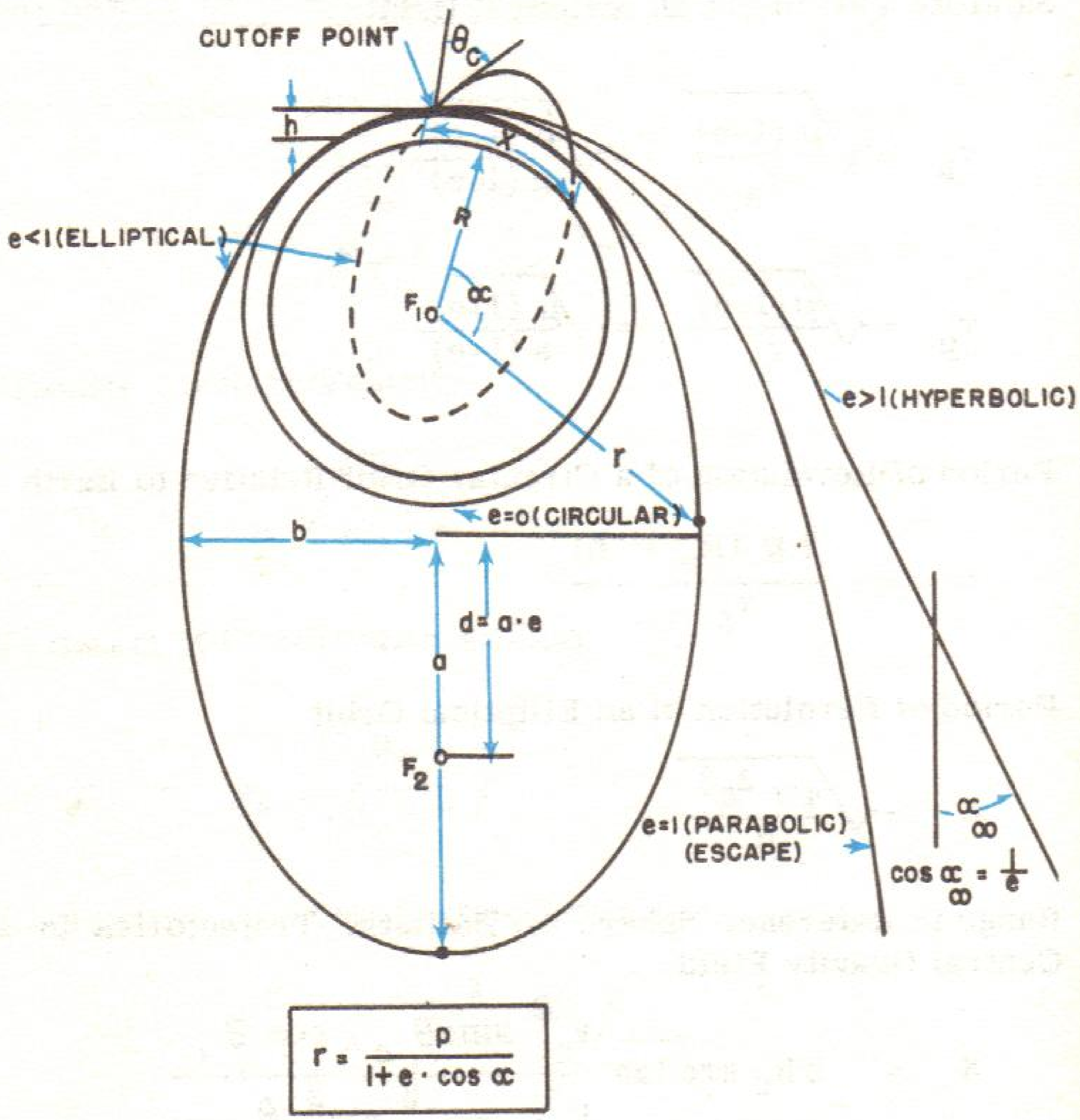
$$t = \sqrt{\frac{4\pi^2 a^3}{\mu}}$$

Range in Reference Sphere of Ballistic Trajectories in a Central Gravity Field

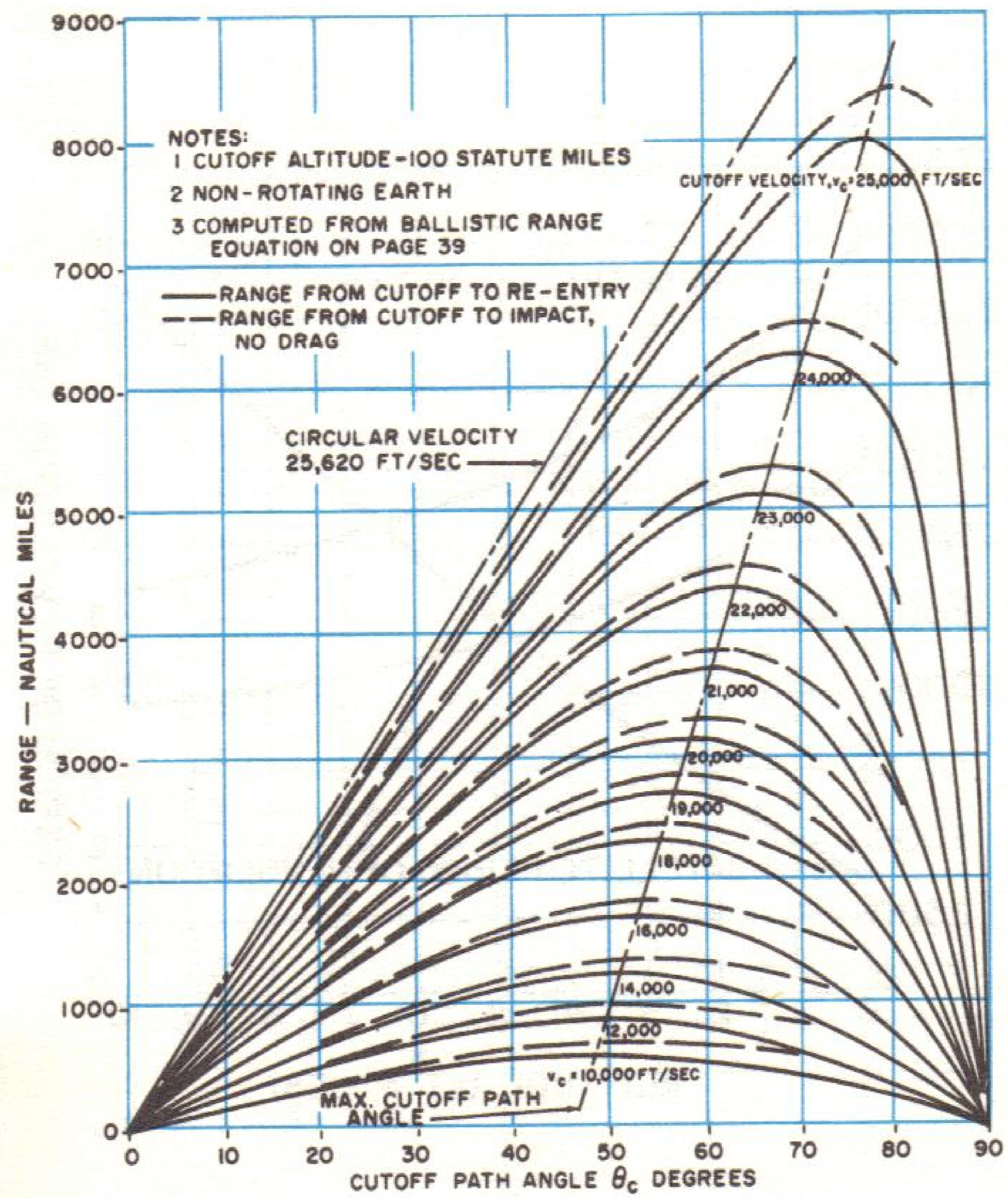
$$X = 2R_c \arctan \frac{v_c^2 \sin \theta_c \cos \theta_c}{R_c g_c - v_c^2 \sin^2 \theta_c}$$

Approximate Range from Cutoff to Impact in a Central Gravity Field (No Drag)

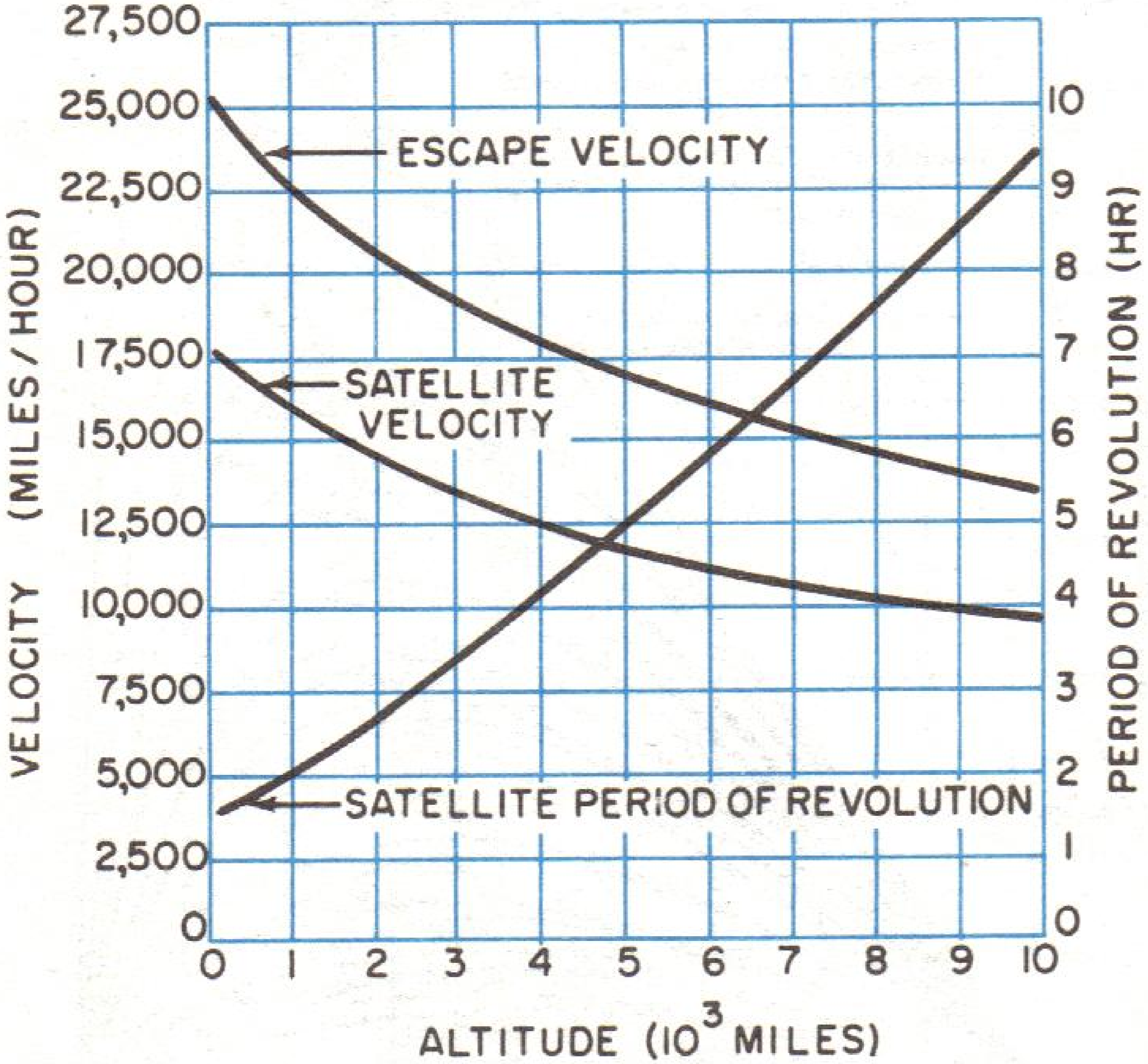
$$X' = X + h_c \tan \theta_c$$



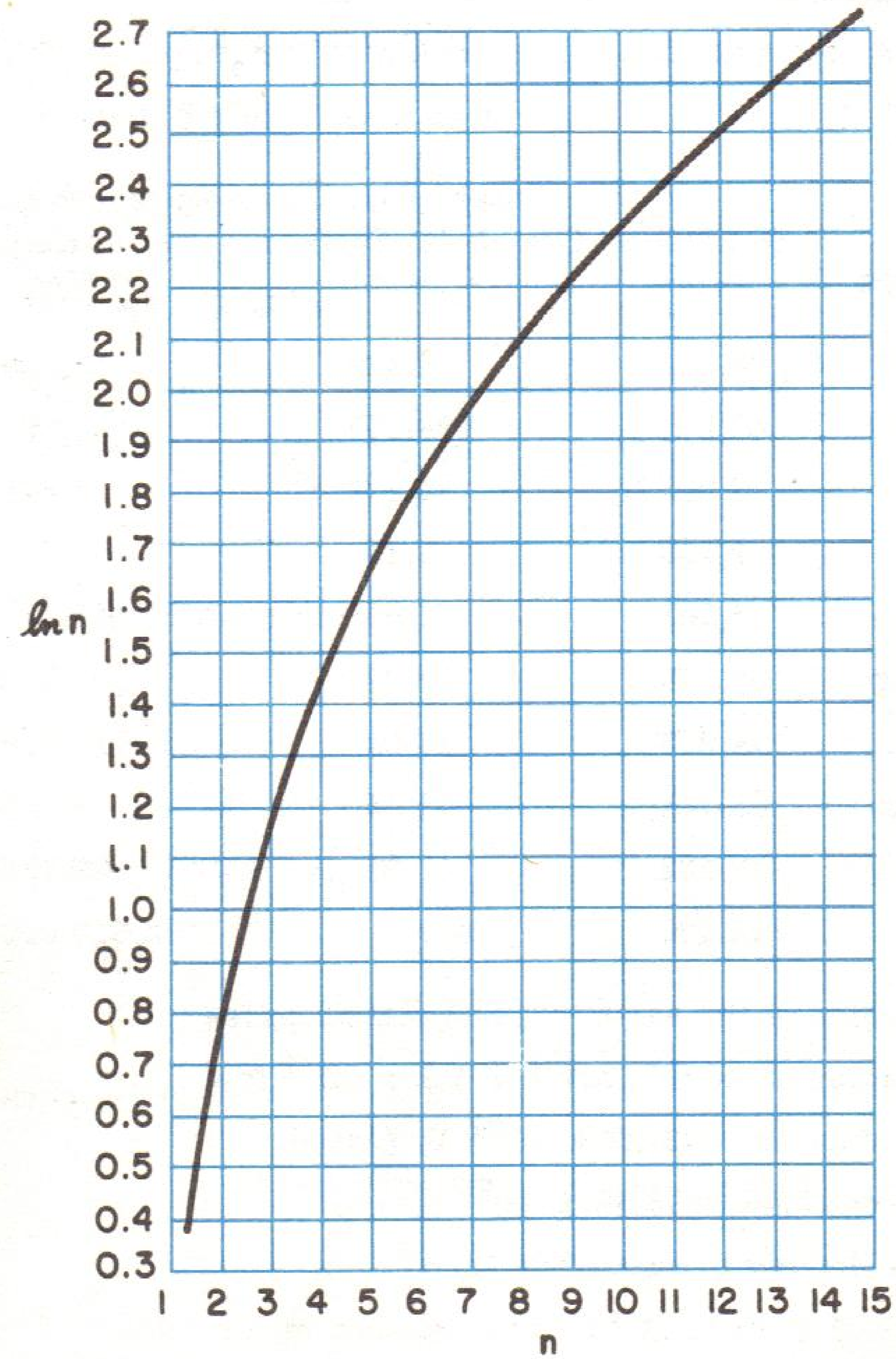
Inertial Trajectories in a Central Gravity Field



Range of Ballistic Trajectories over Reference Sphere 100 miles above Earth



Escape Velocity and Period of Revolution of a Satellite Vehicle as a Function of Altitude



CHARACTERISTIC DATA OF THE SOLAR SYSTEM

Constant of gravitation (G) = 6.664×10^{-8} cm^3/gm sec^2

= 3.44×10^{-8} ft^4/lb sec^4

Planet	Diameter Miles	Acceleration Of Gravity At Surface Ft/Sec^2	Escape Velocity At Surface Ft/Sec
Mercury	3,194	10.449	13,109
Venus	7,842	28.297	33,697
Earth	7,926	32.172	36,677
Moon	2,159	5.19	7,693
Mars	4,263	12.95	16,825
Jupiter	89,229	85.27	197,700
Saturn	74,937	37.62	119,200
Uranus	33,181	33.85	72,490
Neptune	30,882	47.61	82,380
Sun	864,100	900	2,020,000

Mean radius of the earth = 3,963 statute miles

Mean radius of earth's orbit = 4.9×10^{11} feet

Weight of earth = 13.22×10^{24} lb (Avdp)

Volume of earth = 38.38×10^{21} ft^3

Average density of earth=344 lb/ft^3

1 degree of latitude at 40° = 69 statute miles

1 nautical mile = 1' of arc on the earth's surface at the equator = 6080.2 feet

PHYSICAL PROPERTIES

GENERAL PROPERTIES OF GASES

Polytropic

$$P_oV_o^{\,n} = PV^n, \quad \frac{T}{T_o} = \left(\frac{V_o}{V}\right)^{n-1} = \left(\frac{P}{P_o}\right)^{\frac{n-1}{n}}$$

Reversible Adiabatic

$$\frac{P}{P_o} = \left(\frac{V_o}{V}\right)^{k}, \quad \frac{T}{T_o} = \left(\frac{V_o}{V}\right)^{k-1} = \left(\frac{P}{P_o}\right)^{\frac{k-1}{k}} \qquad n = k$$

Constant Temperature

$$\frac{P}{P_o} = \frac{V_o}{V}$$

Constant Volume

$$\frac{T}{T_o} = \frac{P}{P_o}$$

Constant Pressure

$$\frac{T}{T_o} = \frac{V}{V_o}$$

Perfect Gas Law

$$PV = RT, \quad P = \rho gRT$$

PHYSICAL PROPERTIES OF GASES

Gas	Weight of 1 cu ft at standard atmos. and 68°F (lb)	Density relative to air	Gas Constant, R' (ft/°R)	Specific heat at room temperatures C_p (BTU/lb°F)	C_v (BTU/lb°F)	k	Normal Boiling Point (°F)	Weight Density of Liquefied Gas (lb/ft³)		Critical Temp. (°F)	Critical Pressure (Atmospheres)
Acetylene	0.06754	0.897	59.40	0.350	0.2737	1.28	-118	24.9	at +86°F	96.8	62
Air	0.07528	1.000	53.30	0.241	0.1725	1.40	-317.6	57.4	-233	-220.3	37.2
Ammonia	0.04420	0.587	90.77	0.523	0.4064	1.29	- 28	38.1	+ 61	270.3	111.5
Argon	0.1037	1.377	38.70	0.124	0.0743	1.67	-302	87.3	-303	-187.7	48.0
Carbon Dioxide	0.1142	1.516	35.13	0.205	0.1599	1.28	-109	48.0	+ 68	88.0	73.0
Carbon Monoxide	0.07269	0.965	55.19	0.243	0.1721	1.41	-310	53.7	- 90	-220.33	34.53
Helium	0.01039	0.138	386.30	1.250	0.754	1.67	-452	9.18	-456	-450.2	2.26
Hydrogen	0.005234	0.0695	766.80	3.420	2.4350	1.40	-423	4.37	-423	-399.8	12.8
Methane	0.04163	0.553	96.37	0.593	0.4692	1.26	-258	25.9	-263	-116.5	45.8
Nitric Oxide	0.07788	1.034	51.52	0.231	0.1648	1.40	-291	91.7	+ 60	-136.7	65
Nitrogen	0.07274	0.966	55.16	0.247	0.1761	1.40	-320	50.4	-321	-232.8	33.5
Steam	--	0.623	85.81	0.460	0.3600	1.28	+212	62.4	+ 39	705.2	217.72

GENERAL PROPERTIES OF AIR

Symbols

P_o	Standard absolute pressure at sea level	lb/ft^2
T_o	Standard absolute temperature sea level	°R
q	Impact pressure	lb/ft^2
σ	Density Ratio, ρ/ρ_o	none
γ	Specific Weight	lb/ft^3

Specific Weight of Air

$$\gamma = 0.07651\left(\frac{P}{P_o}\right)\left(\frac{T_o}{T}\right) = 1.325\left[\frac{P\text{ (in. Hg)}}{T}\right]$$

Density of Air

$$\rho = 0.002378\left(\frac{P}{P_o}\right)\left(\frac{T_o}{T}\right) = 0.041187\left[\frac{P\text{ (in. Hg)}}{T}\right]$$

Air Density Ratio

$$\sigma = \frac{\rho}{\rho_o} = \left(\frac{P}{P_o}\right)\left(\frac{T_o}{T}\right) = 17.32\left[\frac{P\text{ (in. Hg)}}{T}\right]$$

Speed of Sound in Air

$$C_{fps} = 49.04\sqrt{T}$$

$$C_{mph} = 33.5\sqrt{T}$$

$$C_{knots} = 29.04\sqrt{T}$$

Specific Heat of Air

$$C_p = 0.240\text{ BTU/lb°F}$$

$$C_v = 0.1715\text{ BTU/lb°F}$$

Molecular Weight of Air

$$M = 28.966\text{ lb/Mol}$$

Specific Gas Constant for Air

$$R' = 53.3$$

COMPOSITION OF AIR

The air of the NACA standard atmosphere is assumed to be dry and to have the following composition at all altitudes considered:

Constituent Gas	Mole Percent	Molecular Weight
Nitrogen	78.09	28.016
Oxygen	20.95	32.000
Argon	0.93	39.944
Carbon Dioxide	0.03	44.010
Neon	1.8×10^{-3}	20.183
Helium	5.24×10^{-4}	4.003
Krypton	1.0×10^{-4}	83.7
Hydrogen	5.0×10^{-5}	2.016
Xenon	8.0×10^{-6}	131.3
Ozone	1.0×10^{-6}	48.000
Radon	6.0×10^{-18}	222.0

ICAO ATMOSPHERIC STANDARD

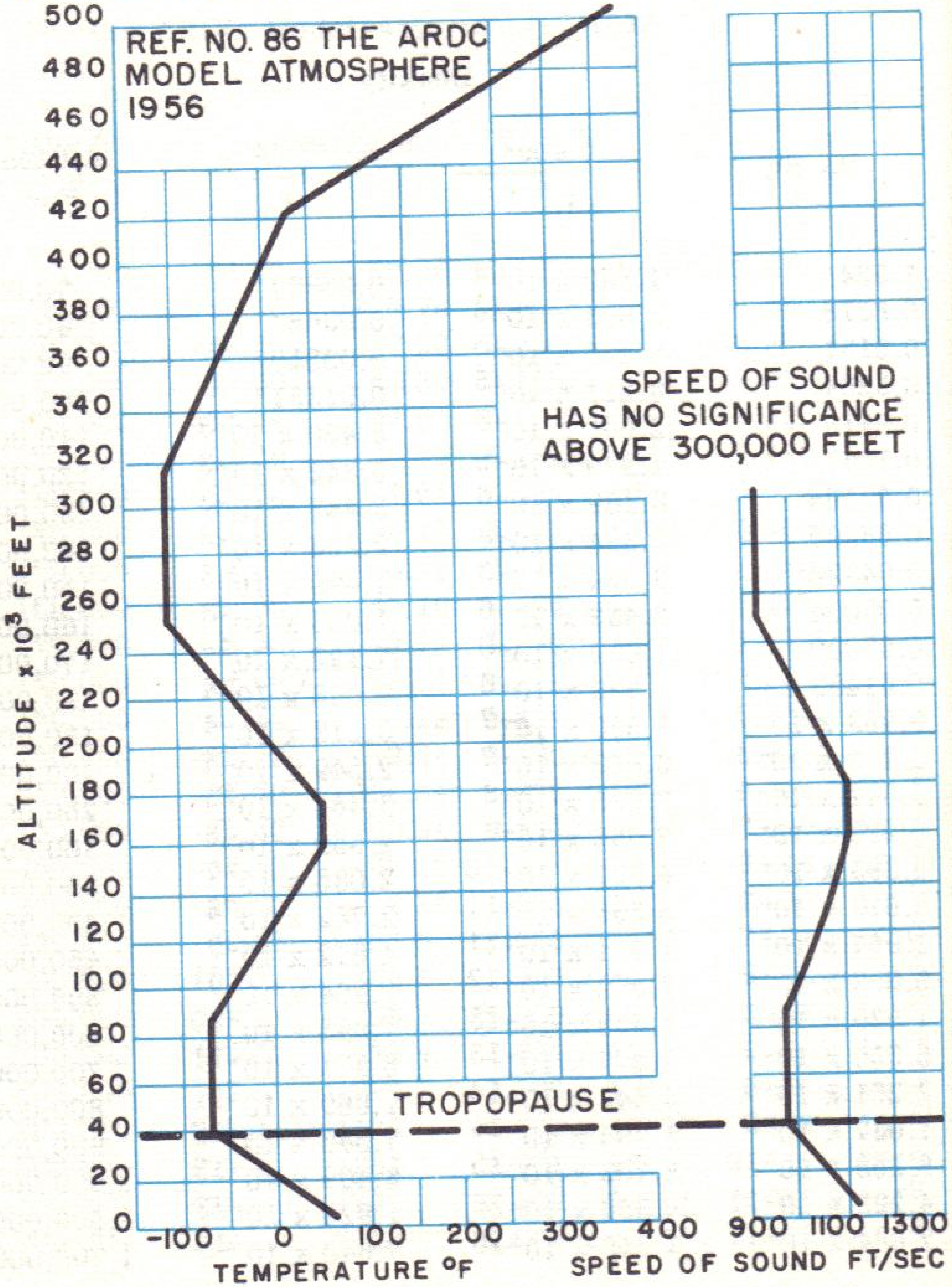
	English	Metric
Standard Values at Sea Level		
Pressure	29.92 in. Hg 2116 lb/ft^2	760 mm Hg 10332.27 kg/m^2
Temperature	59°F	15°C
Absolute temperature	518.688°R	288.16°K
Specific weight	0.076475 lb/ft^3	1.2250 kg/m^3
Mass density	0.0023769 lb sec^2/ft^4	0.12492 kg sec^2/m^4
Standard Values at Altitude		
Isothermal Altitude	36,089.24 ft	11,000 m
Isothermal Temperature	-69.7°F	-56.5°C

STANDARD ATMOSPHERE

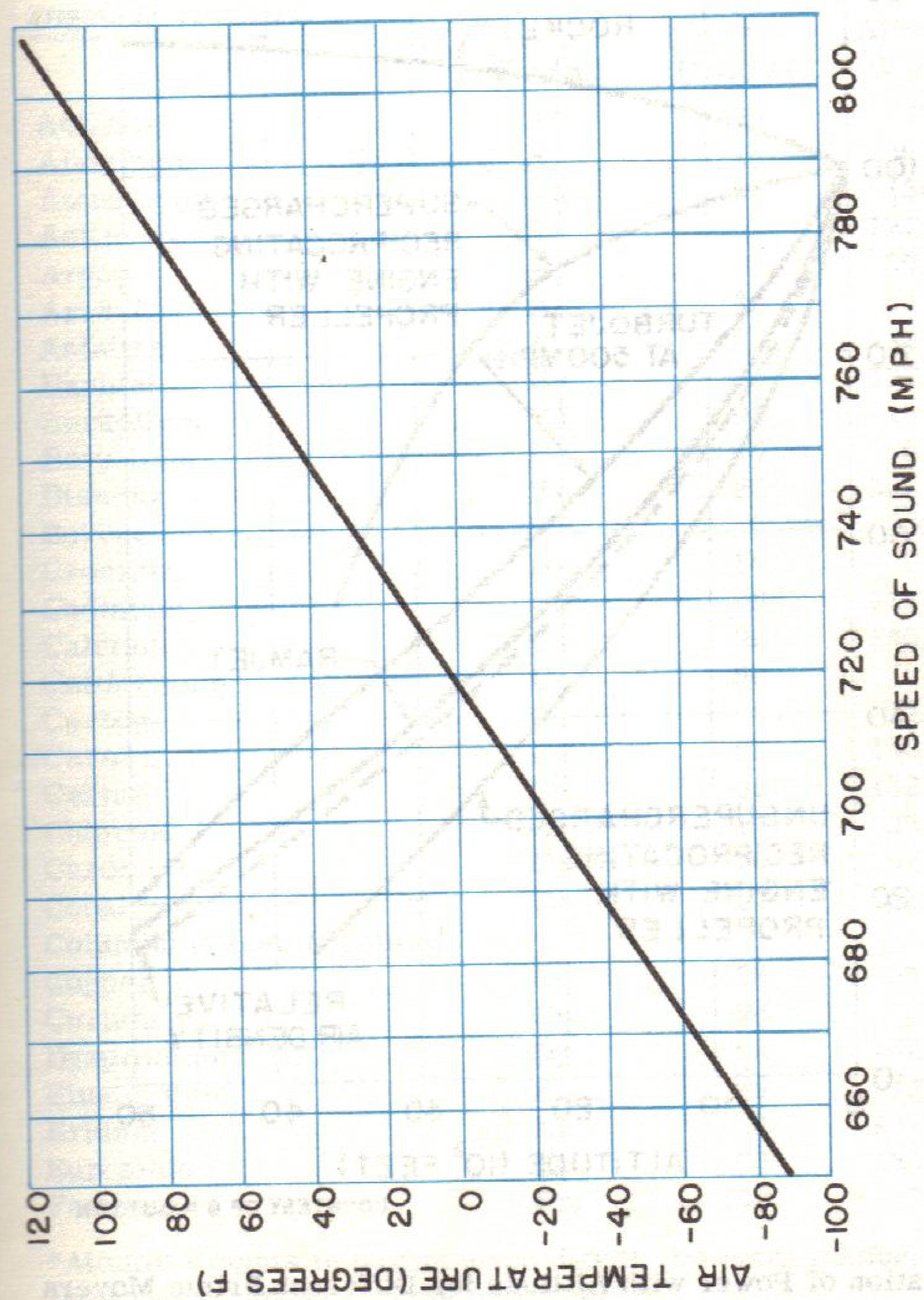
Altitude Feet	Temperature °C	Temperature °F	Pressure lb/in.^{2}	Pressure lb/ft^2	Pressure in. Hg	Density lb sec^2/ft^4	Density ρ/ρ_o
NACA Standard Atmosphere							
0	15.0	59.0	14.69	2116.	29.92	2.377×10^{-3}	1.0000
1000	13.0	55.4	14.17	2041.	28.86	2.308×10^{-3}	0.9711
2000	11.0	51.9	13.67	1968.	27.82	2.241×10^{-3}	0.9428
3000	9.1	48.3	13.17	1897.	26.82	2.175×10^{-3}	0.9151
4000	7.1	44.7	12.69	1828.	25.84	2.111×10^{-3}	0.8881
5000	5.1	41.2	12.23	1761.	24.90	2.048×10^{-3}	0.8617
6000	3.1	37.6	11.78	1696.	23.98	1.987×10^{-3}	0.8359
7000	1.1	34.0	11.34	1633.	23.09	1.927×10^{-3}	0.8106
8000	- 0.8	30.5	10.92	1572.	22.22	1.868×10^{-3}	0.7860
9000	- 2.8	26.9	10.51	1513.	21.39	1.811×10^{-3}	0.7620
10,000	- 4.8	23.3	10.10	1455.	20.58	1.755×10^{-3}	0.7385
11,000	- 6.8	19.8	9.722	1400.	19.79	1.701×10^{-3}	0.7156
12,000	- 8.8	16.2	9.347	1346.	19.03	1.648×10^{-3}	0.6932
13,000	-10.8	12.6	8.986	1294.	18.29	1.596×10^{-3}	0.6713
14,000	-12.7	9.1	8.632	1243.	17.58	1.545×10^{-3}	0.6500
15,000	-14.7	5.5	8.292	1194.	16.89	1.496×10^{-3}	0.6292
16,000	-16.7	1.9	7.965	1147.	16.22	1.447×10^{-3}	0.6090
17,000	-18.7	- 1.6	7.646	1101.	15.57	1.401×10^{-3}	0.5892
18,000	-20.7	- 5.2	7.340	1057.	14.94	1.355×10^{-3}	0.5699
19,000	-22.6	- 8.8	7.042	1014.	14.34	1.310×10^{-3}	0.5511
20.000	-24.6	-12.3	6.753	972.5	13.75	1.266×10^{-3}	0.5328
21,000	-26.6	-15.9	6.475	932.4	13.18	1.224×10^{-3}	0.5150
22,000	-28.6	-19.5	6.206	893.7	12.64	1.183×10^{-3}	0.4976
23,000	-30.6	-23.0	5.946	856.3	12.11	1.143×10^{-3}	0.4807
24,000	-32.5	-26.6	5.696	820.2	11.60	1.103×10^{-3}	0.4642
25,000	-34.5	-30.2	5.453	785.3	11.10	1.065×10^{-3}	0.4481
26,000	-36.5	-33.7	5.219	751.6	10.63	1.028×10^{-3}	0.4325
27,000	-38.5	-37.3	4.994	719.1	10.17	9.919×10^{-4}	0.4173
28,000	-40.5	-40.9	4.776	687.8	9.725	9.567×10^{-4}	0.4025
29,000	-42.5	-44.4	4.567	657.6	9.297	9.225×10^{-4}	0.3881
30,000	-44.4	-48.0	4.364	628.4	8.885	8.893×10^{-4}	0.3741
31,000	-46.4	-51.6	4.169	600.3	8.488	8.570×10^{-4}	0.3605
32,000	-48.4	-55.1	3.981	573.3	8.106	8.255×10^{-4}	0.3473
33,000	-50.4	-58.7	3.800	547.2	7.737	7.950×10^{-4}	0.3345
34,000	-52.4	-62.2	3.626	522.1	7.382	7.653×10^{-4}	0.3220
35,000	-54.3	-65.8	3.458	498.0	7.041	7.365×10^{-4}	0.3099
36,000	-55.0	-69.4	3.296	474.7	6.712	7.086×10^{-4}	0.2981
36,089	-55.0	-69.7	3.283	472.7	6.683	7.061×10^{-4}	0.2971
37,000	-55.0	-69.7	3.142	452.4	6.397	6.759×10^{-4}	0.2844
38,000	-55.0	-69.7	2.994	431.2	6.097	6.442×10^{-4}	0.2710
39,000	-55.0	-69.7	2.854	411.0	5.811	6.139×10^{-4}	0.2583
40,000	-55.0	-69.7	2.720	391.7	5.538	5.851×10^{-4}	0.2462
45,000	-55.0	-69.7	2.139	308.0	4.355	4.601×10^{-4}	0.1936
50,000	-55.0	-69.7	1.682	242.2	3.425	3.618×10^{-4}	0.1522
55,000	-55.0	-69.7	1.323	190.5	2.693	2.845×10^{-4}	0.1197
60,000	-55.0	-69.7	1.040	149.8	2.118	2.238×10^{-4}	0.09414
65,000	-55.0	-69.7	0.8181	117.8	1.665	1.760×10^{-4}	0.07403

No. 86, the ARDC Model Atmosphere, 1956

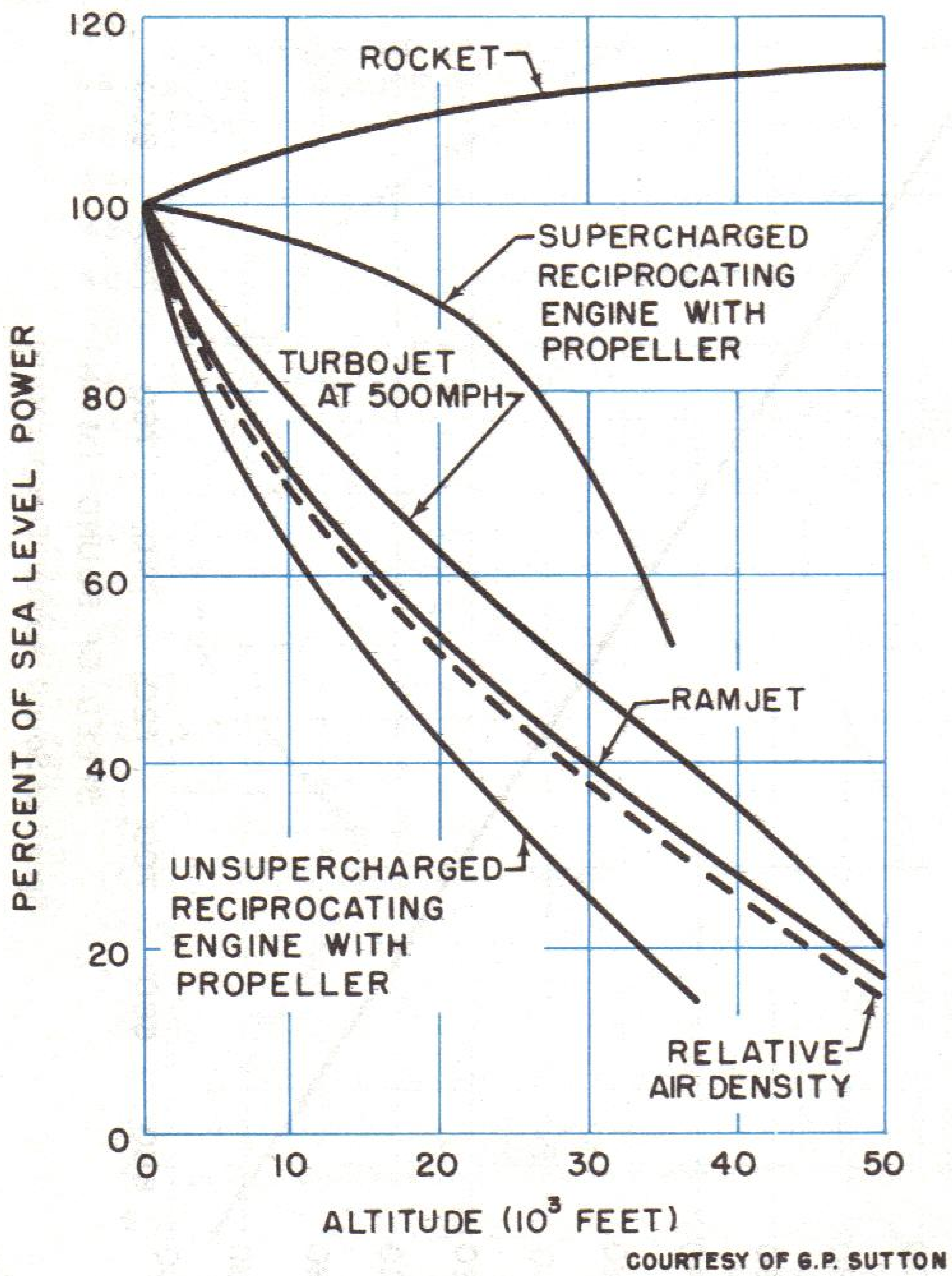
Altitude Feet	Temperature °C	Temperature °F	Pressure $\frac{lb}{in.^2}$	Pressure $\frac{lb}{ft^2}$	Pressure in. Hg	Density $\frac{lb\ sec^2}{ft^4}$	Density $\frac{\rho}{\rho_o}$	Altitude Feet
70,000	-56.50	-69.70	0.6505	93.67	1.324	1.399×10^{-4}	0.05887	70,000
80,000	-56.50	-69.70	0.4036	58.12	0.8218	8.683×10^{-5}	0.03653	80,000
90,000	-49.56	-57.20	0.2520	36.29	0.5131	5.253×10^{-5}	0.02210	90,000
100,000	-40.50	-40.89	0.1603	23.08	0.3264	3.211×10^{-5}	0.01351	100,000
110,000	-31.44	-24.60	0.1038	14.95	0.2113	2.001×10^{-5}	8.420×10^{-3}	110,000
120,000	-22.40	-8.32	6.831×10^{-2}	9.837	0.1391	1.270×10^{-5}	5.342×10^{-3}	120,000
130,000	-13.36	7.94	4.564×10^{-2}	6.573	0.09294	8.189×10^{-6}	3.445×10^{-3}	130,000
140,000	-4.34	24.19	3.094×10^{-2}	4.455	0.06299	5.364×10^{-6}	2.256×10^{-3}	140,000
150,000	4.68	40.42	2.125×10^{-2}	3.060	0.04326	3.564×10^{-6}	1.499×10^{-3}	150,000
160,000	9.50	49.10	1.476×10^{-2}	2.125	0.03004	2.433×10^{-6}	1.023×10^{-3}	160,000
170,000	9.50	49.10	1.026×10^{-2}	1.478	0.02090	1.693×10^{-6}	7.122×10^{-4}	170,000
180,000	4.06	39.31	7.132×10^{-3}	1.027	0.01453	1.199×10^{-6}	5.046×10^{-4}	180,000
190,000	-7.62	18.29	4.894×10^{-3}	0.7047	9.963×10^{-3}	8.589×10^{-7}	3.613×10^{-4}	190,000
200,000	-19.30	-2.74	3.300×10^{-3}	0.4752	6.718×10^{-3}	6.058×10^{-7}	2.549×10^{-4}	200,000
250,000	-76.30	-105.34	3.378×10^{-4}	4.864×10^{-2}	6.877×10^{-4}	7.996×10^{-8}	3.364×10^{-5}	250,000
300,000	-76.30	-105.34	2.568×10^{-5}	3.698×10^{-3}	5.229×10^{-5}	6.065×10^{-9}	2.552×10^{-6}	300,000
350,000	-52.52	-62.53	2.649×10^{-6}	3.814×10^{-4}	5.393×10^{-6}	4.957×10^{-10}	2.085×10^{-7}	350,000
400,000	-16.25	2.76	4.233×10^{-7}	6.096×10^{-5}	8.619×10^{-7}	6.565×10^{-11}	2.762×10^{-8}	400,000
450,000	67.55	153.6	9.660×10^{-8}	1.391×10^{-5}	1.967×10^{-7}	1.111×10^{-11}	4.672×10^{-9}	450,000
500,000	185.3	365.6	3.385×10^{-8}	4.875×10^{-6}	6.892×10^{-8}	2.862×10^{-12}	1.204×10^{-9}	500,000
600,000	402.0	755.7	8.000×10^{-9}	1.152×10^{-6}	1.629×10^{-8}	4.499×10^{-13}	1.893×10^{-10}	600,000
700,000	468.5	875.4	3.854×10^{-9}	5.550×10^{-7}	5.550×10^{-9}	1.277×10^{-13}	5.371×10^{-11}	700,000
800,000	537.3	999.2	1.106×10^{-9}	1.592×10^{-7}	2.251×10^{-9}	4.443×10^{-14}	1.869×10^{-11}	800,000
900,000	607.1	1125	5.092×10^{-10}	7.332×10^{-8}	1.037×10^{-9}	1.794×10^{-14}	7.546×10^{-12}	900,000
1,000,000	677.2	1251	2.581×10^{-10}	3.717×10^{-8}	5.256×10^{-10}	8.103×10^{-15}	3.409×10^{-12}	1,000,000
1,500,000	1025	1878	2.109×10^{-11}	3.037×10^{-9}	4.293×10^{-11}	4.326×10^{-16}	1.820×10^{-13}	1,500,000
1,700,000	1162	2123	1.004×10^{-11}	1.446×10^{-9}	2.044×10^{-11}	1.816×10^{-16}	7.640×10^{-14}	1,700,000



Temperature and Speed of Sound versus Altitude



Speed of Sound versus Temperature



Variation of Power with Altitude for Different Prime Movers

CHEMICAL ELEMENTS

	Symbol	Atomic Number	Atomic* Weight
Actinium	Ac	89	(227)
Aluminum	Al	13	26.98
Americium	Am	95	(243)
Antimony	Sb	51	121.76
Argon	A	18	39.944
Arsenic	As	33	74.91
Astatine	At	85	(210)
Barium	Ba	56	137.36
Berkelium	Bk	97	(249)
Beryllium	Be	4	9.013
Bismuth	Bi	83	209.00
Boron	B	5	10.82
Bromine	Br	35	79.916
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Californium	Cf	98	(249)
Carbon	C	6	12.011
Cerium	Ce	58	140.13
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.457
Chromium	Cr	24	52.01
Cobalt	Co	27	58.94
Columbium (see Niobium)			
Copper	Cu	29	63.54
Curium	Cm	96	(245)
Dysprosium	Dy	66	162.51
Einsteinium	E	99	(253)
Erbium	Er	68	167.27
Europium	Eu	63	152.0
Fermium	Fm	100	(255)

*Atomic weights in parentheses denote the mass numbers of isotopes of longest known half-life.

	Symbol	Atomic Number	Atomic* Weight
Fluorine	F	9	19.00
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.26
Gallium	Ga	31	69.72
Germanium	Ge	32	72.60
Gold	Au	79	197.0
Hafnium	Hf	72	178.50
Helium	He	2	4.003
Holmium	Ho	67	164.94
Hydrogen	H	1	1.0080
Indium	In	49	114.82
Iodine	I	53	126.91
Iridium	Ir	77	192.2
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.92
Lead	Pb	82	207.21
Lithium	Li	3	6.940
Lutetium	Lu	71	174.99
Magnesium	Mg	12	24.32
Manganese	Mn	25	54.94
Mendelevium	Mv	101	(256)
Mercury	Hg	80	200.61
Molybdenum	Mo	42	95.95
Neodynium	Nd	60	144.27
Neon	Ne	10	20.183
Neptunium	Np	93	(237)
Nickel	Ni	28	58.71
Niobium (Columbium)	Nb	41	92.91
Nitrogen	N	7	14.008
Nobelium	No	102	(258)
Osmium	Os	76	190.2
Oxygen	O	8	16.0000

	Symbol	Atomic Number	Atomic* Weight
Palladium	Pd	46	106.4
Phosphorus	P	15	30.975
Platinum	Pt	78	195.09
Plutonium	Pu	94	(242)
Polonium	Po	84	(210)
Potassium	K	19	39.100
Praesodymium	Pr	59	140.92
Promethium	Pm	61	(145)
Protactinium	Pa	91	(231)
Radium	Ra	88	226.05
Radon	Rn	86	(222)
Rhenium	Re	75	186.22
Rhodium	Rh	45	102.91
Rubidium	Rb	37	85.48
Ruthenium	Ru	44	101.1
Samarium	Sm	62	150.35
Scandium	Sc	21	44.96
Selenium	Se	34	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.880
Sodium	Na	11	22.991
Strontium	Sr	38	87.63
Sulfur	S	16	32.066
Tantalum	Ta	73	180.95
Technetium	Tc	43	(99)
Tellurium	Te	52	127.61
Terbium	Tb	65	158.93
Thallium	Tl	81	204.39
Thorium	Th	90	232.05
Thulium	Tm	69	168.94
Tin	Sn	50	118.70

*Atomic weights in parentheses denote the mass numbers of isotopes of longest known half-life.

	Symbol	Atomic Number	Atomic Weight
Titanium	Ti	22	47.90
Tungsten	W	74	183.86
Uranium	U	92	238.07
Vanadium	V	23	50.95
Xenon	Xe	54	131.30
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.92
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

MISCELLANEOUS CONSTANTS

Mechanical equivalent of heat	4.182 joule cal^{-1}
Electronic charge	4.80294×10^{-10} esu
Mass of electron, m_e	9.1066×10^{-28} gm
Mass of proton, m_p	1.67248×10^{-24} gm
Mass of α particle, m_α	6.6442×10^{-24} gm
Mass of hydrogen atom, m_H	1.67339×10^{-24} gm
Avogadro's number, N_0	6.0228×20^{23} $(\text{gm mol})^{-1}$
Planck constant, h	6.6254×10^{-27} erg sec
Boltzmann constant, k	1.38049×10^{-16} erg $(°k)^{-1}$
Velocity of light in vacuum, c	2.997928×10^{10} cm sec^{-1}
	186,282 miles sec^{-1}

1 mil (electric definition), measure of wire diameter = 0.001 in.
1 mil (angular measure) = 360°/6400 (Army Ordnance)
1 mil (angular measure) = 1/1000 radian (Naval Ordnance)
1 Navy mil = 1.0186 Army mil
Heat equivalent of fusion of water, 79.24 cal per gram
Heat equivalent of vaporization of water, 535.9 cal per gram

$e = 2.71828$
$\log_e 10 = 2.30258$
$\pi = 3.14159$

PHYSICAL PROPERTIES OF REFRACTORY MATERIALS

Material	Melting or Decomposition Temp. °F	*True Specific Gravity	**Apparent Specific Gravity	Linear Coefficient of Expansion/°C x 10^{-6}	Thermal Conductivity BTU/hr/ft²/in./°F	Specific Heat
Chromic Oxide	3614	5.21		7.0 - 12.0		
Alumina	3660	3.97	2.95	8.1	18	0.27
Silicon Carbide	3990	3.17	2.82	4.5	56	0.19
Niafrax A			2.77	6.7	113	
Lt. Wt. Niafrax			2.30			
Boron Carbide	4440	2.51	2.51	4.5		
Zircon	4532	4.56	3.32	5.1	12	0.132
Beryllium Oxide	4658	3.02	2.87	9.3	1080-1380	0.40
Zirconia	4892	6.27	4.40	11.0	5	0.168
Magnesia	5072	3.58	2.50	14.3	23	0.187
Thoria	5522	9.69	7.34	9.4		0.06
Titanium Carbide	5748	4.25				
Graphite	6332	2.25	1.60	1.5	600	0.34

* True Specific Gravity is based on a solid mass.
** Apparent Specific Gravity accounts for the voids that exist in refractories.

PHYSICAL PROPERTIES OF METALS

Materials		Specific Gravity	Density lb/in.^{3}	Melting Point °F	Ultimate Tensile Strength x 10^3 psi	Modulus of Elasticity x 10^6 psi	Coefficient of Thermal Expansion (32°F - 212°F) x 10^{-6} in./in./°F	Thermal Conductivity (32°F - 212°F) BTU/ft^{2}hr°F/in.
Aluminum EC-0		2.7	0.098	1195-1215	12	10.0	13.7	1,630
Al Alloys (Wrought)	1100-0	2.71	0.098	1190-1215	13	10.0	13.7	1,540
	3003-0	2.73	0.099	1190-1210	16	10.0	12.9	1,340
	3004-0	2.72	0.098	1165-1205	26	10.0	12.9	1,130
	2014-T6	2.80	0.101	950-1180	70	10.6	12.5	1,070
	2024-T4	2.77	0.100	935-1180	68	10.6	12.6	840
	5052-0	2.68	0.097	1100-1200	28	10.2	13.2	960
	6061-T6	2.70	0.098	1080-1200	45	10.0	13.0	1,070
Al Alloys (Cast)								
Sand	195-T6	2.78	0.101	970-1170	36	10.3	12.2	1,310
Perm. Mold	195-T6	2.78	0.101	970-1170	40	10.3	12.2	1,310
Sand	355-T6	2.66	0.096	1015-1150	35	10.3	12.2	990
Perm. Mold	355-T6	2.66	0.096	1015-1150	43	10.3	12.2	990
Sand	356-T6	2.63	0.095	1035-1135	33	10.3	11.9	1,050
Perm. Mold	356-T6	2.63	0.095	1035-1135	40	10.3	11.9	1,050
Beryllium		1.85	0.066	2345	35-95	36-44	13.3	1,130
Brass Yellow (Hard)		8.47	0.306	1710	74	14	10.5	830
Bronze-Manganese Hard Temper		8.36	0.302	1645	90	15	11.2	700
Bronze-Phosphor (5%) Hard Temper		8.86	0.320	1920	100	15	9.4	565
Bronze-Aluminum Hard		7.78	0.281	1900	105	15	9.2	490
Beryllium Copper Hard Temp		8.23	0.297	1750	190	18	9.2	650
Copper Hard Temp		8.92	0.322	1980	52	16	9.3	2,700
Muntz Metal Hard Temp		8.40	0.303	1660	80	13	10.8	870
Cupro-Nickel (70-30) Cold-Rolled		8.94	0.323	2240	80	20	8.5	200
Dowmetal C Cast & H. T.		1.82	0.066	1110	40	6.5	14	464
Gold (Pure) Hard Temp		19.32	0.698	1945	32	13	7.8	2,000
Iron Wrought (Hot Rolled)		7.70	0.278	2750	48	29	6.7	418
Cast (As Cast)		7.20	0.260	2150	25	13	6.7	310
Malleable (As Cast)		7.32	0.264	2250	55	25	6.6	435

Materials	Specific Gravity	Density lb/in.^{3}	Melting Point °F	Ultimate Tensile Strength x 10^3 psi	Modulus of Elasticity x 10^6 psi	Coefficient of Thermal Expansion (32°F - 212°F) x 10^{-6} in./in./°F	Thermal Conductivity (32°F - 212°F) BTU/ft^2 hr °F/in.
K-Monel (Wrought) Hot Rolled	8.47	0.306	2400-2460	150	26	7.8	130
Inconel (Wrought) Hot Rolled	8.51	0.307	2540-2600	100	31	6.4	104
Magnesium Wrought J-1 Alloy	1.8	0.065	950-1150	44	6.5	14.4	553
Nickel (Wrought) Hard Temp	8.89	0.321	2615-2635	105	30	7.2	420
Palladium Hard Temp	11.98	0.432	2830	47	17	6.5	490
Platinum Hard Temp	21.40	0.772	3225	36	24	4.9	480
Silver (Pure) Hard Temp	10.50	0.379	1760	43	10.5	10.6	2900
Steel SAE 1020 Hot Rolled	7.86	0.284	2760	69	30	6.7	360
Stainless Steel							
Type 304 Annealed	8.02	0.29	2550-2650	85	28	9.6	113
Type 316 Annealed	8.02	0.29	2500-2550	90	28	8.9	113
Type 321 & 347 Annealed	7.92	0.286	2550-2600	85	28	9.3	110
Type 410 Annealed	7.75	0.28	2700-2790	75	29	5.5	173
Steel Alloys							
4130 Annealed	7.85	0.283	2500-2600	80	29	12.4	288
4140 Annealed	7.85	0.283	2500-2600	95	29	12.3	288
8630 Annealed	7.84	0.283	2500-2600	80	29	12.7	288
Tantalum Annealed	16.6	0.60	5425	42	27	3.57	375
Tin Annealed	7.29	0.263	450	2.38	7.1	11.7	455
Titanium (Pure) Cold Rolled	4.54	0.164		145	16	3.3	118
Titanium Alloy Fe, Cr, Mo Annealed	4.68	0.169		140	16	5.0	80-120
Zinc	7.15	0.258	786	21	--	13-18	780

CONVERSION FACTORS

AREA

Multiply	By	To Obtain
Acres	43,560	Square feet
	0.4047	Hectares
	1.562×10^{-3}	Square miles
Square centimeters	0.1550	Square inches
	1.08×10^{-3}	Square feet
Square kilometers	0.3861	Square miles
Square inches	6.4516	Square centimeters
Square feet	144	Square inches
	0.111	Square yards
Square yards	1296	Square inches
	0.8361	Square meters
Square miles	2.5900	Square kilometers
	640	Acres

DENSITY

Multiply	By	To Obtain
Grams per cubic centimeter	62.428	Pounds per cubic foot
	0.03613	Pounds per cubic foot
Pounds per cubic inch	1728	Pounds per cubic foot
	27.68	Grams per cubic centimeter

ENERGY

Multiply	By	To Obtain
BTU's	777.97	Foot-pounds
	2.930×10^{-4}	Kilowatt-hours
	251.98	Gram-calories
	1054.8	Joules
Ergs	9.4805×10^{-11}	BTU's
	1.0	Dyna-centimeters
	7.37×10^{-8}	Foot-pounds
	1.02×10^{-3}	Gram-centimeters
	1×10^{-7}	Joules
	2.389×10^{-5}	Kilogram-calories
Calories	3.968×10^{-3}	BTU's
	4.186	Joules
Horsepower-hour	2544	BTU's
	1.98×10^{6}	Foot-pounds
	641.3	Kilogram-calories
Joules	9.480×10^{4}	BTU's
	0.73756	Foot-pounds
	2.388×10^{-4}	Kilogram-calories
	0.10179	Kilogram-meters
	1.0	Watt-seconds
	2.778×10^{-4}	Watt-hours
	3.725×10^{-7}	Horsepower-hours
Kilogram-calories	3.9685	BTU's
	3087.4	Foot-pounds
	426.85	Kilogram-meters
Kilogram-meters	7.233	Foot-pounds
	9.8066×10^{7}	Ergs

FORCE

Multiply	By	To Obtain
Dynes	1.020×10^{-3}	Grams
	2.248×10^{-6}	Pounds
	7.233×10^{-5}	Poundals
Grams	15.432	Grains
	0.03527	Ounces
	0.00220	Pounds
	980.665	Dynes

HEAT TRANSFER COEFFICIENT

Multiply	By	To Obtain
BTU/(hr)(ft^2)(°F)	0.0001355	Gm cal/(sec)(cm^2)(°C)
	1.929×10^{-6}	BTU/(sec)(in.^{2})(°F)
	0.0005669	watts/cm^2°C

LENGTH

Multiply	By	To Obtain
Centimeters	0.2837	Inches
	0.03281	Feet
	1×10^8	Angstroms
	1×10^4	Microns
Meters	39.37	Inches
	3.281	Feet
	1.0936	Yards
Kilometers	0.6214	Miles
	0.5396	Nautical miles

Multiply	By	To Obtain
Miles	5280	Feet
	0.8684	Nautical miles
	1760	Yards
	1.6093	Kilometers
Nautical miles	6080.2	Feet
	1.85325	Kilometers
Light years	5.9×10^{12}	Miles
	9.46×10^{12}	Kilometers

POWER

Multiply	By	To Obtain
BTU's per minute	12.96	Foot-pounds per second
	0.2520	Kilogram-calories per minute
BTU's per second	1.414	Horsepower
	1054.8	Watts
Horsepower	33,000	Foot-pounds per minute
	550	Foot-pounds per second
	76.040	Kilogram-meters per second
	1.0139	Metric horsepower
	0.707	BTU's per second
	2545	BTU's per hour
	745.2	Watts

Multiply	By	To Obtain
Horsepower, metric	75	Kilogram-meters per second
	0.9863	Horsepower
	41.83	BTU's per minute
	542.5	Foot-pounds per second
	10.54	Kilogram-calories per minute
	735.5	Watts
Kilowatts	0.9483	BTU's per second
	737.6	Foot-pounds per second
	0.2389	Kilogram-calories per second
	1.3410	Horsepower
	3414	BTU's per hour

PRESSURE

Multiply	By	To Obtain
Atmospheres	76.0	Centimeters of mercury
	29.921	Inches of mercury
	33.93	Feet of water
	10332	Kilograms per square meter
	14.696	Pounds per square inch
	2116.2	Pounds per square foot
	1.0133	Bars

Multiply	By	To Obtain
	1.0332	Kilograms per square centimeter
Centimeters of mercury	5.3524	Inches of water
	0.4460	Feet of water
	0.1934	Pounds per square inch
	27.845	Pounds per square foot
	135.95	Kilograms per square meter
Feet of water	0.02947	Atmospheres
	0.4335	Pounds per square inch
	62.378	Pounds per square foot
Inches of mercury	0.03342	Atmospheres
	13.60	Inches of water
	1.133	Feet of water
	0.4912	Pounds per square inch
	70.727	Pounds per square foot
	345.32	Kilograms per square meter
Inches of water	0.03609	Pounds per square inch
	5.1981	Pounds per square foot
	25.38	Kilograms per square meter

Multiply	By	To Obtain
Kilograms per square centimeter	0.9678	Atmospheres
	14.22	Pounds per square inch
Kilograms per square meter	0.00142	Pounds per square inch
	0.20482	Pounds per square foot
	0.00328	Feet of water
	0.1	Grams per square centimeter
Pounds per square inch	70.31	Grams per square centimeter

THERMAL CONDUCTIVITY

Multiply	By	To Obtain
BTU/(hr)(ft^2)(°F per ft)	0.00413	Gm-cal/(sec) (cm^2) (°C per cm)
	12	BTU/(hr) (ft^2) (°F per in.)
	0.0173	Watts/(cm^2) (°C/cm)

TEMPERATURE

°C = 5/9(F-32)
°F = 9/5 C+32
0°C = 273.16°K
0°F = 459.688°R

VELOCITY

Multiply	By	To Obtain
Feet per minute	0.01136	Miles per hour
	0.01829	Kilometers per hour
	0.0580	Centimeter per second
	0.01667	Feet per second
Feet per second	0.6818	Miles per hour
	1.097	Kilometers per hour
	30.48	Centimeters per second
	0.3048	Meters per second
	0.5921	Knots
Knots	1.0	Nautical miles per hour
	1.6889	Feet per second
	1.1515	Miles per hour
	1.8532	Kilometers per hour
	0.5148	Meters per second

Multiply	By	To Obtain
Meters per second	3.281	Feet per second
	2.237	Miles per hour
	3.600	Kilometers per hour
Miles per hour	1.467	Feet per second
	0.4470	Meters per second
	1.609	Kilometers per hour
	0.8684	Knots

VISCOSITY

Multiply	By	To Obtain
Radians per second	57.296	Degrees per second
	0.1592	Revolutions per second
	9.55	Revolutions per minute

ABSOLUTE VISCOSITY

Multiply	By	To Obtain
Poise	1.0	gm/cm sec
	1.0	dyne sec/cm^2
	100	Centipoise
Centipoise	0.000672	lb/ft sec
	0.0000209	lb sec/ft^2
	2.42	lb/ft hr

Multiply	By	To Obtain

KINEMATIC VISCOSITY

Multiply	By	To Obtain
Stoke	1.0	cm^2/sec
	0.155	in.^{2}/sec
	0.001076	ft^2/sec
	density (gm/cm^3)	Poise

VOLUME

Multiply	By	To Obtain
Barrels	42	Gallons (Oil)
	31.5	Gallons
Cubic centimeters	10^{-3}	Liters
	0.0610	Cubic inches
Cubic feet	28317	Cubic centimeters
	1728	Cubic inches
	0.03704	Cubic yards
	7.481	Gallons
	28.32	Liters
Cubic inches	16.387	Cubic centimeters
	0.01639	Liters
	4.329×10^{-3}	Gallons
	0.01732	Quarts (liquid)
Gallons, imperial	277.4	Cubic inches
	1.201	U.S. gallons
	4.546	Liters
Gallons, U.S. (liquid)	231	Cubic inches
	0.1337	Cubic feet

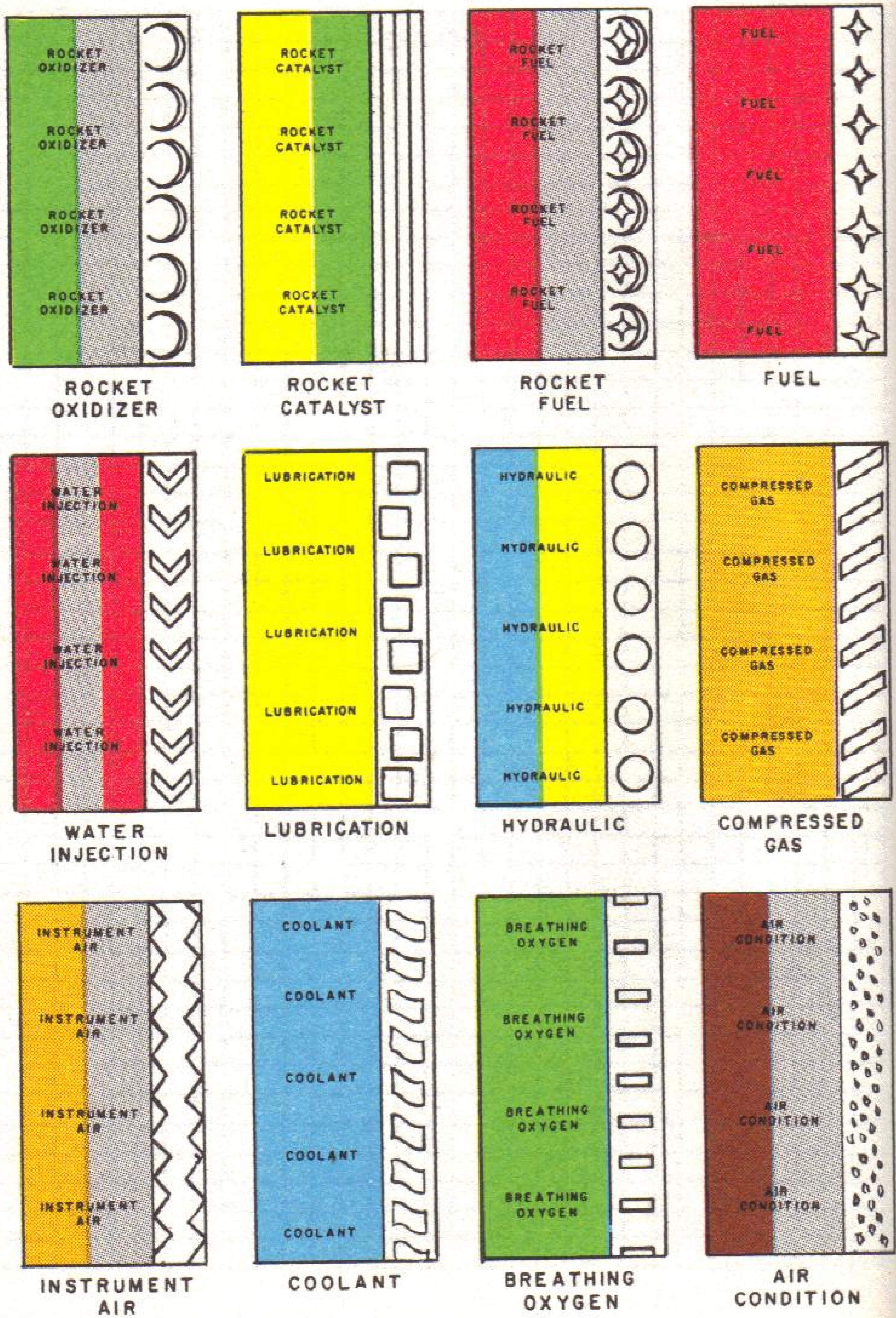
Multiply	By	To Obtain
Gallons, U.S. (liquid)	3.785	Liters
	0.8327	Imperial gallons
	128	Fluid ounces
Ounces, fluid	29.57	Cubic centimeters
	1.805	Cubic inches
Liters	0.2642	Gallons
	0.0353	Cubic Feet
	1.0567	Quarts
	61.025	Cubic inches
Quarts, U.S. (liquid)	0.0334	Cubic feet
	57.749	Cubic inches
	0.9463	Liters

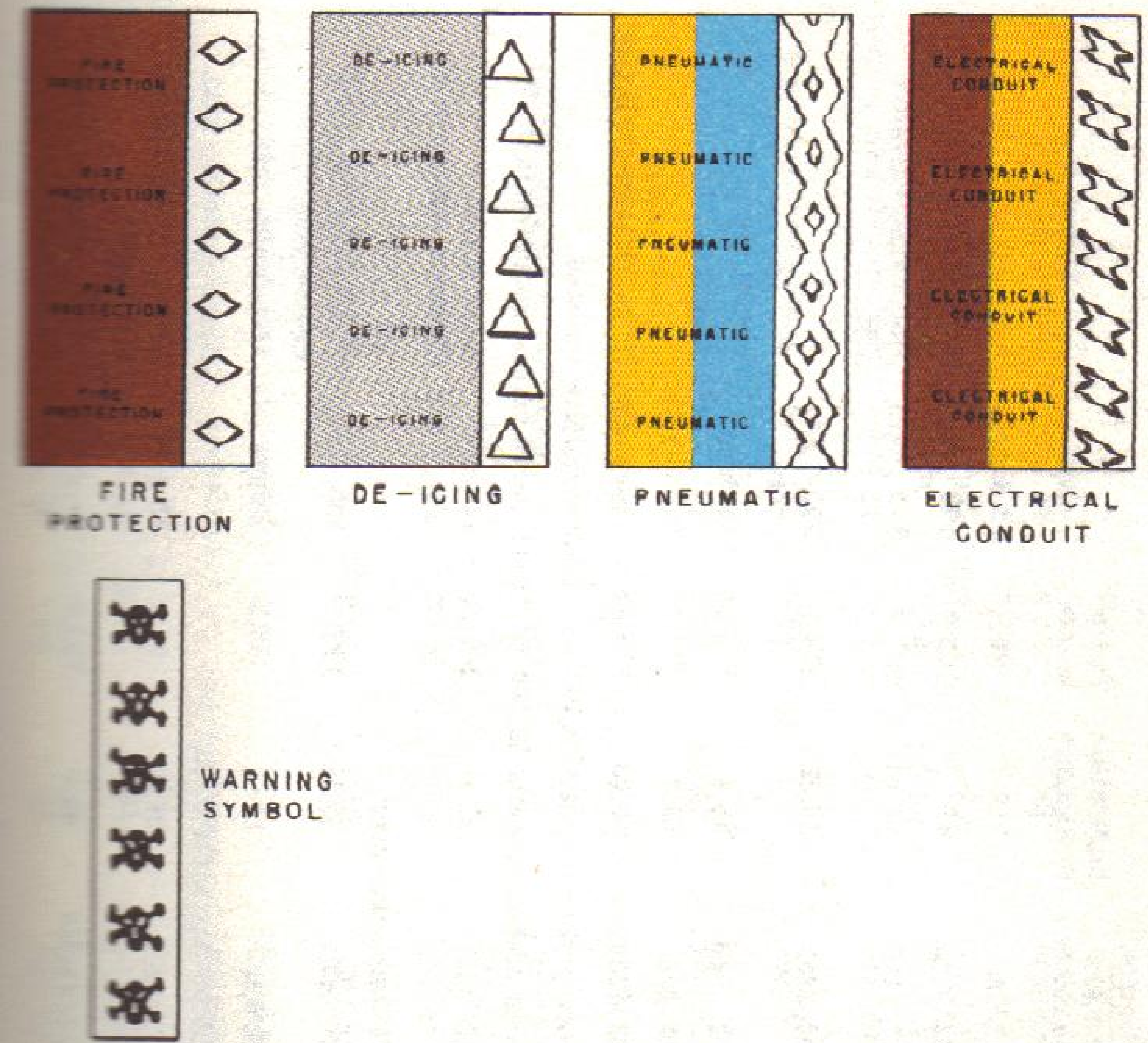
WEIGHT

Multiply	By	To Obtain
Grams	15.432	Grains
	0.03527	Ounces (avdp)
	0.002205	Pounds (avdp)
	1000	Milligrams
	0.001	Kilograms
	980.67	Dynes
Kilograms	2.205	Pounds (avdp)
	35.27	Ounces (avdp)
Pounds (avdp)	7000	Grains
	16.0	Ounces
	1.215	Pounds (troy)
	0.4536	Kilograms

Multiply	By	To Obtain
Tons (long)	2240	Pounds (avdp)
	1016	Kilograms
Tons (metric)	1000	Kilograms
	2205	Pounds (avdp)
	1.102	Tons (short)
Tons (short)	2000	Pounds (avdp)
	907.2	Kilograms
	0.9072	Tons (metric)

NOTES





FLUID LINE IDENTIFICATION COLORS

The fluid line identifications represent designations for systems only. For coding lines which do not fall into one of these systems the contents shall be designated by black lettering on a white background.

Pressure transmitter lines shall be identified by the same colors as the lines from which pressure is being transmitted.

Filler lines, vent lines, and drain lines from functions or related functional equipment shall be identified by the same identifications as the function lines.

No.	Name	Launch Date	Weight in lbs	Perigee / Apogee in miles	Inclination to Equator	Period in min	Life	Remarks
1.	Sputnik I	10/4/57	184	142/588	65°	96.17	92 days	
2.	Sputnik II	11/3/57	1120	140/1038	65°	103.7	162 days	Dog lived one week.
3.	Explorer I	1/31/58	30.8	217/1199	33.34	107.9	3-5 years	Discovered radiation belt.
4.	Vanguard I	3/17/58	3.25	406/2463	34.25	134.1	200-1000 years	
5.	Explorer III	3/26/58	31	121/1746	33.4	115.87	93 days	
6.	Sputnik III	5/15/58	7000	105/238	65.3	89.7	692 days	
7.	Explorer IV	7/26/58	38.4	163/1380	50.29	110.27	85-91 days	More radiation belt data.
8.	Pioneer I	10/11/58	84.4	Moon probe; reached 70,700 mi., proved radiation a band.				
9.	Pioneer III	12/6/58	12.95	Moon probe; reached 63,580 mi., discovered second radiation belt.				
10.	Project Score	12/18/58	8750	110/920	32.3	101.46	34 days	Atlas ICBM. Communications test.
11.	Lunik I	1/2/59	3245	450-day solar orbit				
12.	Vanguard II	2/17/59	20.74	346/2050	32.88	125.4	100+ yrs.	Cloud cover scanner. Precessing
13.	Discoverer I*	2/28/59	1300	99/605	87	95.9	5 days	First polar orbit.
14.	Pioneer IV	3/3/59	13.4	406.95-day solar orbit				Space radiation data.
15.	Discoverer II*	4/13/59	1610	142/220	89.8	90.5	13 days	Capsule returned but lost in Arctic.
16.	Explorer VI	8/7/59	142	115/24,618	46.9	753.6	1+ year	First photos of earth from space.
17.	Discoverer V*	8/13/59	1700	136/450	90	94	47 days	Capsule still in higher orbit.
18.	Discoverer VI*	8/19/59	1700	138/537	90	95.28	63 days	Capsule separated but lost.
19.	Lunik II	9/12/59	858.4	Impacted on moon 9/13/59. Approximately 35 hour flight time.				
20.	Vanguard III	9/18/59	100	321/2321	33.3	129.9	30-40 yrs.	Magnetic & micro-metorite studies.
21.	Lunik III	10/4/59	614	24,840/ 292,000	polar	15 days	199 days	First photos of moon far side.
22.	Explorer VII	10/13/59	91	344/673	50.3	101.2	20-30 yrs	Still transmitting.
23.	Discoverer VII*	11/7/59	1700	104/550	90	95	19 days	
24.	Discoverer VIII*	11/20/59	1700	120/1056	90	103.7	110 days	Capsule returned but lost.
25.	Pioneer V	3/11/60	94.8	$(74.9/92.3) \times 10^6$ solar orbit,		period	311.6 days	Record distance radio transmission.
26.	Tiros I	4/1/60	270	429/465	48.3	99.2	50-100 yrs	Cloud cover photos transmitted.
27.	Transit IB	4/13/60	265	229/455	51	95.6	16(?) mo.	Broadcast navigation signals.
28.	Discoverer XI*	4/15/60	1700	109/380	80.1	92.4	11 days	Capsule ejected but lost.
29.	Sputnik IV	5/15/60	10,008 total	198/198 (191/429)	64.9 (64.9)	91 (94.25)	n.a. n.a.	Separated into 8 pieces + (dummy-manned capsule)
30.	Midas II*	5/24/60	5000	300/320	33	94.4	4+ yrs	Missile infrared detector.

BELL AEROSYSTEMS COMPANY — DIVISION OF BELL AEROSPACE CORPORATION

No.	Name	Launch Date	Weight in lbs.	Perigee Apogee in miles	Inclination to Equator	Period in min.	Life	Remarks
31.	Transit IIA	6/22/60	265	389/650	polar	101.7	50(?) yrs	Also piggy-back "Grebi"!
32.	Discoverer XIII*	8/10/60	1700	161/436	polar	94.1	97 days	Capsule recovered from water.
33.	Echo I	8/12/60	137.4	945/1049	48.6	118.3	1(?) yr	100' aluminized plastic sphere
34.	Discoverer XIV*	8/18/60	1700	111/504	79.65	94	21(?) days	Capsule recovered in air.
35.	Sputnik V	8/19/60	10,141	191/191	64.9	91	27 hrs	Zoo capsule recovered.
36.	Courier IB	9/4/60	500	602/752		106.9	1(?) yr	Active-repeater communications
37.	Discoverer XV*	9/12/60	1700	130/470	polar			Capsule returned but lost.
38.	Explorer VIII	11/3/60	90	259/1423	50	112.75	3(?) mo	Direct sampling upper ionosphere.
39.	Discoverer XVII*	11/2/60	2100	/615	polar	96.45	46 days	Capsule recovered in air.
40.	Tiros II	11/23/60	280	386.9/453.2	48.53	98.37		Infrared scanner, cloud photos.
41.	Sputnik VI	12/1/60	10,060	115/164	65°	88.6	1 day	Zoo satellite burned on re-entry.
42.	Discoverer XVIII*	12/7/60	2100	150/450	polar	94		Capsule recovered in air.
43.	Discoverer XIX*	12/20/60	2100	130/400	polar	93	1 mo.	Missile-infrared detector.
44.	Sputnik VII	2/4/61	14,293	139/186	64.9	89.80	22 days	
45.	Venus Probe	2/12/61	1419	Interplanetary Probe: aphelion 1.0190 A.U., perihelion 0.7183 A.U.				
46.	Sputnik VIII	2/12/61		123/198		89.7	13 days	
47.	Explorer IX	2/16/61	15	438/1555	38.86	118.1		Polka dot balloon.
48.	Discoverer XX*	2/17/61	2450	176/393	80.91	93.8		No attempt to recover 300-lb capsule.
49.	Discoverer XXI*	2/18/61	2100	154/475	80.74	94.8		Infrared equipment, background radiation.
50.	Transit IIIB/Lofti	2/21/61		117/511	23.86	94.5	37 days	Orbit achieved, malfunction hampered quality of Transit data.
51.	Sputnik IX	3/9/61	10,340	113.9/154.5			1 day	
52.	Sputnik X	3/25/61	10,330	111/150	64.54	88.42	1 day	
53.	Explorer X	3/25/61	79	100/112500	33.0	50.2		Optical-pumping magnetometer.
54.	Discoverer XXIII*	4/8/61	2100	183/324	82.31	92.8		Capsule ejected in wrong direction.
55.	Vostok I	4/12/61	10,418	108.76/187.66	65.07	89.1	1 day	Yuri Gagarin, first Russian Cosmonaut.
56.	Explorer XI	4/27/61	82	302/1113	28.80	107.9	1-3 years	Measures atmospheric absorption of stellar gamma rays.
57.	Mercury-Redstone	5/5/61	2000	Suborbital Flight				Cmdr. Sheppard, first U.S. Astronaut.
58.	Discoverer XXV*	6/16/61	2100	139.1/251.6	82.11	90.87	2 days	

NO.	Name	Launch Date	Weight in lbs.	Perigee/Apogee in miles	Inclination to Equator	Period in min	Life	Remarks
59.	Transit IV-A	6/29/61	175	547/620	67.0	103.8	1 year	Three-in-one launch with Injun/Greb III.
60.	Injun/Greb III	6/29/61	Injun 40 Greb III 55	548/619	67.0	103.8		Failed to separate but transmitting.
61.	Discoverer XXVI*	7/7/61	2100	142/352	82.93	92.6		Systems evaluation of Agena B. Capsule recovered.
62.	Tiros III	7/12/61	285	457/511	47.8	100.3		Transmitting cloud cover weather pictures.
63.	Midas III*	7/12/61	3500	2084/2197	91.17	161.5		Infrared early warning.
64.	Mercury-Redstone	7/21/61	2000	Suborbital Flight				Capt. Grissom, second U.S. Astronaut.
65.	Vostok II	8/6/61	10,430	110.3/115.3	64.0	88.6	2 days	Gherman Titov, second Russian Cosmonaut; 17-1/2 orbits.
66.	Explorer XII	8/15/61	83	183/48059	33.09	1593	1 year	Study Van Allen belts and energetic particles in space.
67.	Ranger I*	8/23/61	675	105/312.5	32.90	91.1		Failed to achieve planned orbit.
68.	Explorer XIII*	8/25/61	187	174.60/606.34	36.42	97.27	3 days	Orbit achieved.
69.	Discoverer XXIX*	8/30/61	2100	140/345	82.14	91.0	3 months	Reliability testing of Agena B.
70.	Discoverer XXX*	9/12/61		144/306	82.71	91.9		
71.	Discoverer [illegible]	9/17/61		138/202	82.7	90.0		