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Design Analysis
Circle Ellipse Engine

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Abstract

The Circle Ellipse Engine is a unique, patented, internal combustion engine design based on my life experience. I have been fortunate to receive several patent awards throughout my 40 years of experience as an engineer and scientist in radar, sonar, satellite communications, medical devices, space transportation, and military parts reinvention. I capped my career with 10 years of continuous work developing another patented rotary engine. These past 5 years, now retired, I crystallized my thinking and approach to invent this incredibly simple, low-cost fossil-fuel Circle Ellipse Engine.

The Circle Ellipse Engine reinvents the functionality of the centuries-old reciprocating engine. Instead of pistons, driven by the rotation of a crankshaft, the Circle Ellipse Engine offers continuous power every revolution. Its relationship of an elliptical surface surrounding a round rotor forms the necessary 4-step Otto-Cycle geometry every rotation, at half the RPM of a reciprocating engine. This eliminates the crankshaft, camshaft, valve lifters, rocker arms, connecting rods, wrist pins, timing chains, and a host of other components, significantly reducing engine size and weight. It is ideal for insertion into every application where small size and weight are primary factors, such as unmanned aerial vehicles (drones). The secondary obvious advantage is a marked reduction in host size and weight, generally translating to the ability to carry increased fuel and/or payload.

This is a comprehensive design analysis. The analysis includes technical formulae based a small number of assumption, and leverages heavily on industry documented constants for fuel, air, density, etc.

I am confident that you will have a positive reaction to this design analysis. It allows technical evaluation to measure the effects on changes to the baseline engine design, such as size, RPM, fuel, etc, and quickly determine the estimated horsepower, torque, and fuel consumption values.

Because the entire Circle Ellipse Engine is 3D modeled in parametric equations, a drawing package is readily available in days, with complete and accurate estimates of performance, weight, and cost.

Robert Grisar
Circle Ellipse Engine Company
Founder and President

Inputs

Gasoline Engines Enter G, Diesel Engines Enter D	G

Constants	Value	Units
1 kJ/kg	0.43	BTU/lb
Pi	3.1416	:1 ratio
1 Horsepower	2542	BTU/hr
1 Horsepower	550	ft-lb/sec
Universal Gas Constant	0.287	kJ/kg °K
Minutes per Hour	60	min/hr
Number cubic inches per cubic foot	1728	:1 ratio

Initial Tem & Pressure Environment	Value	Units
Initial Temperature *(32F for STP)* (T1)	32	°F
Initial Temperature *(273K for STP)* (T1)	273	°K
Initial Pressure *(14.696 for STP)* (P1)	14.7	lb/in^2
Initial Pressure *(1 atm for STP)* (P1)	1	atm
Air Density *(0.0807 at STP)*	0.0807	lbs/cu ft
Est Peak temp during Combustion	1500	°K
Ave. Gas Specific Heat Air (Cp)	1.010	kJ/kg °K
Ave. Gas Specific Heat Air (Cv)	0.718	kJ/kg °K
Ratio of Specific Heats (cp/cv) K=	1.407	ratio

Fuel: Gasoline	Value	Units
Fuel Density	6.073	lbs/gal
Fuel Heating Energy (Qr)	124,884	BTU/gal
Fuel Heating Energy (Qr)	20,853	BTU/lb
Stoich. Fuel Mass Fraction (f)	0.064	lb fuel/lb air
Air to Fuel Ratio	15.0	:1 ratio
Stoichiometric Ratio	14.7	:1 ratio
Equivalence Fuel Ratio (f)	0.98	:1 ratio
1 cu ft fuel =	7.408	gal

Efficiency Factors & Assumptions		
Est Volumetric Efficiency *(Typ = 0.85)*	0.85	Handbook
Est. Friction Factor *(Piston = 0.10)*	0.1	Handbook
Est. Engine Heat Loss Factor	0.1	Handbook
Est Losses (pressure, efficiency)	0.2	Estimate

RPM	Value	Units
RPM	2200	rev/min

Material Density	Value	Units
Material Factor Steel=0.286	0.286	Handbook
Material Factor Alum=0.095	0.095	Handbook

Vane	Value	Units
Number of Vanes	12	number
Number Combust Chambers	12	number
Vane Travel	1.000	in
Vane Thickness	0.250	in
Rotor & Vane Width	6.000	in

Rotor	Value	Units
Ellipse Minor Axis (in)	3.000	in
Ellipse Major Axis (in)	4.000	in
Rotor Radius	3.000	in

End Plate / Housing	Value	Units
Number End Plates	2	#
End Plate Thickness	1	in
Housing Thickness	1	in

Combustion Layer	Value	Units
Hemisphere depth =	0.75	in
Layer L indent Tl =	0.5	in
Layer W indent Tw =	0.1875	in

Color Legend for All Workbook Values

	Universal Constants
	CE Engine Constants
	Calculated Value
	Gasoline or Diesel
	Desired Value

Outputs

Engine Size	Value	Units
Engine Displacement	47.549	cu in
One Combustion Chamber Disp	3.962	cu in
Engine Width	8.000	in
Engine Diameter	10.000	in

Volume and Weight	Value	Units
Engine Volume	628.320	cu in
Engine Weight	95.731	lb
Auxiliary Equipment Weight	135.000	lb
Total Engine Weight w/Accessories & Fluids	230.731	lb

Fuel Utilization & Efficiency	Value	Units
Fuel Consumption	2.573	gal/hr
Mass of Air through Engine (minute)	4.153	lbs air/min
Mass of Air through Engine (hr)	249.151	lbs air/hr
Engine Air Flow	51.456	cfm
Available Time for Combustion/Expansion	27.273	msec
Available Time for Fuel Injection	9.091	msec
Combustion Thermal Efficiency tEc)	55.080	%

Horsepower & Torque	Value	Units
Compression Ratio	8.507	ratio
Gross Theoretical Horsepower (calculated)	70.608	HP
Power to Compress Air	1.031	HP
Power Lost to Exhaust	0.683	HP
Net Theoretical Horsepower (calculated)	68.894	HP
Gross Theoretical Torque	168.561	ft-lb
Fuel Flow Rate (Ma x f x f)	2.573	ga//hr
Estimated Combustion Thermal Efficiency	55.080	%
Estimated Horsepower per Pound	0.738	HP/lb
Estimated HP per cu in Displacement	1.485	HP/cu in

Displacement

Variable	Description	Value	Units
Pi	Pi Constant	3.1416	:1 ratio
VE	Est. Volumetric Efficiency *(Typical = 0.85)*	0.85	#
	Est. Friction Factor *(Typical = 0.10)*	0.1	#
	Est. Engine Heat Loss Factor	0.1	#
	Est. Engine Losses (pressure, efficiencies)	0.2	#
VT	Vane Travel (VT)	1.00	in
Vt	Vane Thickness (Vt)	0.25	in
CR	Compression Ratio	8.5	:1 ratio
RPM	Engine Speed (RPM)	2200	rev/min
a	Ellipse Major Axis (a)	4.00	in
b	Ellipse Minor Axis (b)	3.00	in
r	Rotor Radius (r)	3.00	in
VN	Number of Vanes (VN)	12	#
Vw	Rotor & Vane Width (Vw)	6.00	in

HP = Displacement x Pressure x RPM x (Est. Combustion Thermal Efficiency)

Therefore:

Solving for Displacement (Dt)
Dt (displacement) = (ellipse cross section - rotor cross section - no. vanes * average vane travel) * vane width

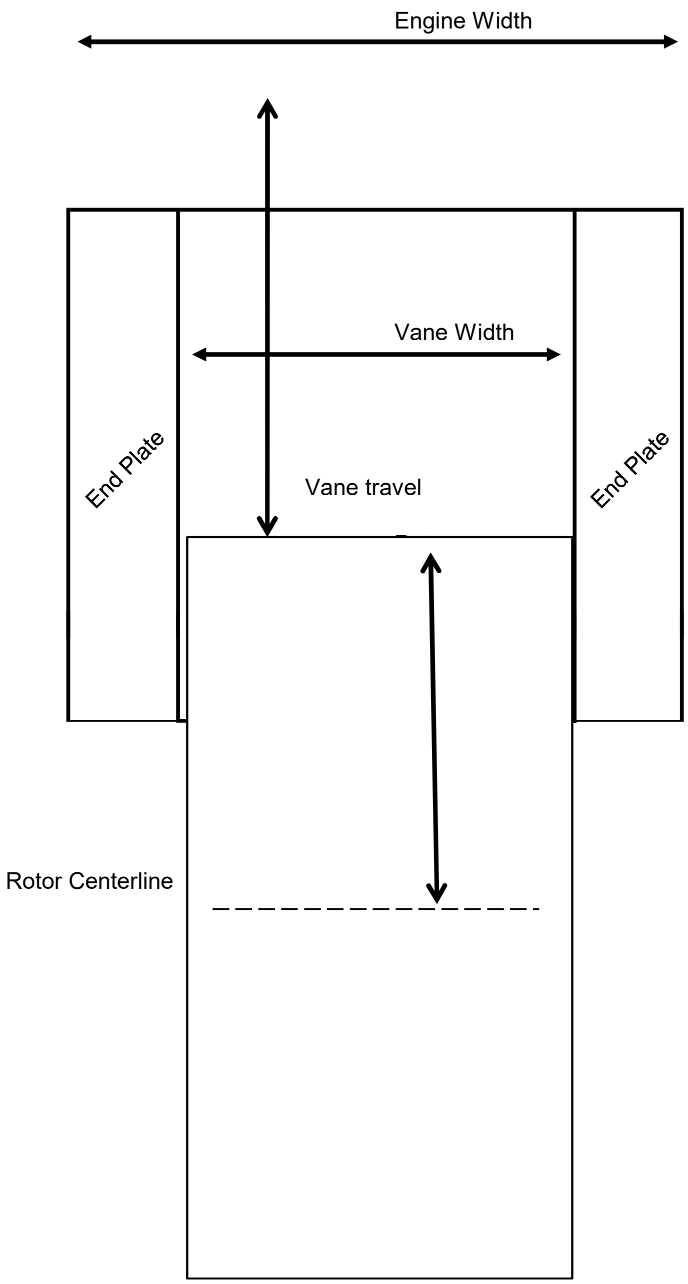
Dt (displacement) = (π*a*b - π*r^2 - # vanes (VN) x vane thickness (Vt) x average vane travel (VT/2)) * vane width (Vw)

Dc (Single Chamber Displacement (cu in)) = Dt / VN

Solutions

Dt = (Pi*a*b - Pi*r*r - VN*VT / 2 * Vt) * Vw	**47.549**	cu in
Dc = Single Chamber Displacement (cu in)	**3.962**	cu in
Est. Combustion Thermal Efficiency {VE * (1-Friction) * (1-Heat Loss) * (1-Engine Losses) * 100}	**55.080**	%

Cross Section



Description	Value	Units
Vane Width	6.000	in
Vane Travel	1.000	in
Rotor Radius	3.000	in
Ellipse Major Axis	4.000	in
End Plate Width	1.000	in
Housing Thickness	1.000	in
Engine Diameter =	10.000	in
Engine Width =	8.000	in

Air-Water-Oil Passageways

Constants	PI	3.1416
Volume	cu in/cu ft	1728

AIR/EXHAUST			
	End Plate Inl	units	ousing outlet
Diameter	0.50	size	0.25
quantity	4	qty	18
tot dia	0.7854	sq in	0.88358

Air density	0.0807	lb/cu ft
rpm	2200	rev/min
flow	0.0807	lb air/min

LUBRICATION OIL IN FITTINGS			
	inlet	units	outlet
threads	0.05	size	0.05
quantity	6	qty	6
tot dia	0.011781	sq in	0.011781

density	6.073	lb/cu ft
rpm	2200	rev/min
flow	0.091089	lb oil/min

WATER			
	End Plate Inl	units	outlet
threads	5/8-18	size	5/8-18
quantity	2	qty	2
tot dia	0.614	sq in	0.614

density	62.4	lb/cu ft
rpm	2200	rev/min
flow	48.74661	lb H2O/min

LUBRICATION OIL THRU DRIVESHAFT			
	inlet	units	outlet
threads	0.25	size	0.1
quantity	1	qty	36
tot dia	0.049088	sq in	0.282744

density	6.073	lb/sq in
rpm	2200	rev/min
flow	0.379536	lb oil/min

MANIFOLD OIL					
inlet			outlet		
quantity	1		quantity	1	6
diameter	0.25		diameter	0.25	0.05
sq in	0.049		sq in	0.049	0.012

Weight

Engine Component

Basic Engine	Value	Units
Pi	3.14160	:1 ratio
Ellipse Minor Axis (in)	3.0	in
Ellipse Major Axis	4.0	in
Engine Width (h)	8.0	in
Engine Diameter	10.0	in
Engine Total Volume (PI x R^2 x h)	628	in^3
Less Calculated displacement	47.5	in^3
Material Factor *(Steel=.286)*	0.286	factor
Material Factor *(Al=.095)*	0.095	factor
Engine Weight (Volume x Density)	95.7	lbs
Auxiliary Equipment Weight	135.0	lbs
Engine Wet Weight w/Accessories	230.7	lbs

Note: Estimated weight does not account for voids, and liquids (oil, water).

Accessory Components

Lubrication System:	Weight	Units
Oil	10	lbs
Oil Radiator	5	lbs
Pump, Filter/Housing, Lube oil reser	10	lbs
Fuel pump/accumulator/control system		
Pump / Injectors	10	lbs
Filter, Accumulator & Misc. Plumbin	5	lbs
Sensors & Misc. Controls	5	lbs
Engine Cooling System:		
Coolant	20	lbs
Radiator	20	lbs
Coolant Pump & Plumbing	10	lbs
Electrical & Control System		
Starter/Alternator	10	lbs
Battery	15	lbs
Wiring	5	lbs
Instrumentation	5	lbs
Controls, Sensors & Misc.	5	lbs
Auxiliary Equipment Weight	135	lbs

Compression Ratio

Variables	
PI =	3.1416
ellipse major a =	3.000
ellipse minor b =	4.000
rotor r =	3.000
width w =	6.000
hemisphere depth =	0.75
Layer L indent Tl =	0.5
Layer W indent Tw =	0.1875
Number of Vanes =	12
Vane Thickness =	0.25

Area One Circle Sector	
Circle Sector =	PI x r²/12
A-circle =	2.356

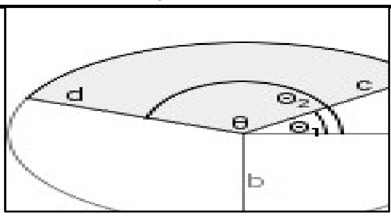
Combustion Layer Volume	
length L =	2 x r - 2 x Tl
L =	5.000
width W =	PI 2r/#V-Vt-2Tw
W =	0.946
height H =	average depth
H =	0.055
volume V1 =	L x W x H
V1 =	0.260

Hemisphere Pocket	
sphere volume =	4/3*s³
sphere volume =	1.767
hemi volume =	sphere volum/2
hemi volume =	0.884

Compress Ratio Summary		
ellipse sector =	4.118	2.380
circle sector =	-2.356	-2.356
minus vane =	-0.225	-0.011
subtotal area =	1.536	0.012
width =	6.000	6.000
width x area =	9.219	0.074
+ combust layer =	0.260	0.260
+ hemisphere =	0.884	0.884
totals =	10.363	1.218
Compress Ratio =	8.507	

Maximum Ellipse Sector Area (-15° to +15°)

Θ1 (degrees) =	-15.000
Θ1 (radians) =	-0.262
Θ2 (degrees) =	15.000
Θ2 (radians) =	0.262
Θ2 - Θ1 (degrees) =	30.000
Θ2 - Θ1 (radians) =	0.524
a =	4.000
b =	3.000



Maximum Vane Area	
Vane-length =	c - b
V-length =	0.900
Vane thickness =	0.25
Vane Area =	0.225

where c = √ a² * b² / [a² * sin²(Θ1) + b² * cos²(Θ1)]

c = 3.900

where d = √ a² * b² / [a² * sin²(Θ2) + b² * cos²(Θ2)]

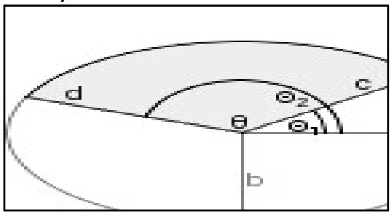
d = 3.900

where A-max = ab/2 * { θ - atan[(b-a)sin(2Θ2) / (a+b+(b-a)cos(2Θ2))] + atan[(b-a)sin(2Θ1) / (a+b+(b-a)cos(2Θ1))] }

A-max = 4.118

Minimum Ellipse Sector Area (75° to +115°)

Θ1 (degrees) =	75.000
Θ1 (radians) =	1.309
Θ2 (degrees) =	105.000
Θ2 (radians) =	1.833
Θ (degrees) =	30.000
Θ (radians) =	0.524
a =	4.000
b =	3.000



Minimum Vane Area	
Vane-length =	c - b
V-length =	0.045
Vane thickness =	0.25
Vane Area =	0.011

where c = √ a² * b² / [a² * sin²(Θ1) + b² * cos²(Θ1)]

c = 3.045

where d = √ a² * b² / [a² * sin²(Θ2) + b² * cos²(Θ2)]

d = 3.045

where A-min = ab/2 * { θ - atan[(b-a)sin(2Θ2) / (a+b+(b-a)cos(2Θ2))] + atan[(b-a)sin(2Θ1) / (a+b+(b-a)cos(2Θ1))] }

A-min = 2.380

Combustion Time

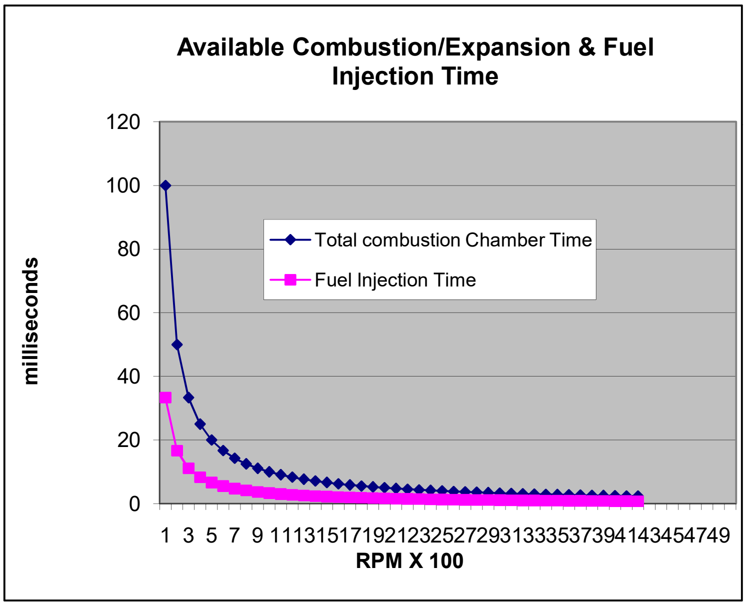
RPM	Combustion Chamber Time (msec)	Available Fuel Injection Time (msec)
100	100.000	33.333
200	50.000	16.667
300	33.333	11.111
400	25.000	8.333
500	20.000	6.667
600	16.667	5.556
700	14.286	4.762
800	12.500	4.167
900	11.111	3.704
1000	10.000	3.333
1100	9.091	3.030
1200	8.333	2.778
1300	7.692	2.564
1400	7.143	2.381
1500	6.667	2.222
1600	6.250	2.083
1700	5.882	1.961
1800	5.556	1.852
1900	5.263	1.754
2000	5.000	1.667
2100	4.762	1.587
2200	4.545	1.515
2300	4.348	1.449
2400	4.167	1.389
2500	4.000	1.333
2600	3.846	1.282
2700	3.704	1.235
2800	3.571	1.190
2900	3.448	1.149
3000	3.333	1.111
3100	3.226	1.075
3200	3.125	1.042
3300	3.030	1.010
3400	2.941	0.980
3500	2.857	0.952
3600	2.778	0.926
3700	2.703	0.901
3800	2.632	0.877
3900	2.564	0.855
4000	2.500	0.833
4100	2.439	0.813
4200	2.381	0.794

Description	Value	Units
Number of Engine Vanes	12	number
Number Vanes In Combustion	2	number
Engine Speed (RPM)	2200	rev/min

Total Combustion Chamber

1/(Rev/min x 4 cycle segments/Rev) x	**27.273**	msec

Total Combustion Chamber Time		
r of Vanes in Combustion Quadrant =		
Time Available for Fuel Injection per	**9.091**	msec



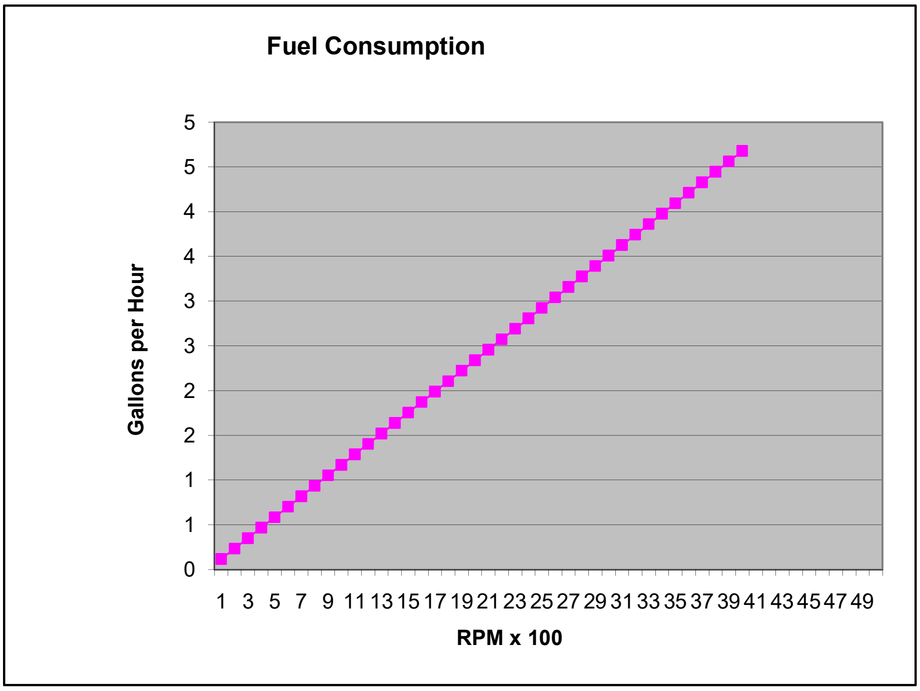
Fuel Consumption

Description	Value	Units	Formula
Engine Speed (RPM)	2200	rev/min	
Total Displacement (DISP)	47.549	cu in	
Displacement per Combustion Chamber	3.962	cu in	Displacement (cu in) / chambers
Number of Vanes	12	#	
Air Fuel Ratio (AFR)	15	:1 ratio	
Stoichiometric Ratio (AFRs)	14.7	:1 ratio	
Equivalence Fuel Ratio (f)	0.98	:1 ratio	Stoichiometric Ratio (AFRs) / Air Fuel Ratio (AFR)
Initial Temperature (32F for STP) (T1)	32	°F	
Initial Temperature (273K for STP) (T1)	273	°K	
Initial Pressure (14.696 for STP) (P1)	14.7	lb/in^2	
Initial Pressure (1 atm for STP) (P1)	1.000	atm =	
Air Density (0.0807 at STP)	101.325	kPa	atm x 101.325 kPa per atm
Volumetric Efficiency (VE)	0.85	%	
Air Density (0.0807 at STP)	0.0807	lbs/cu ft	(P1/(R x T1) x kg/cu m))
Mass of Air (Ma) through Engine	4.153	lbs/min	(VE x Pa x DISP X RPM / 1728)
Stoichiometric Fuel Mass Fraction (f)	0.064	lbs fuel/lbs air	
Fuel Density	6.073	lbs/gal =	
Fuel Density	44.99	lbs/cu ft	Fuel Density (lb/gal) x 7.408 gal/cu ft
Fuel Flow Rate (FFR) (Ma x f x f)	0.260	lb/min =	Mass Air (Ma)xEquiv Fuel Ratio(f)xStoich Fuel Mass (f)
Fuel Flow Rate (Ma x f x f)	0.043	gal/min =	FFR / Fuel Density (gal/min)
Fuel Flow Rate (Ma x f x f)	2.573	gal/hr	FFR gal/min x 60 min/hr (gal/hr)
Engine Air Flow	51.456	cfm =	Mass of Air (Ma) / Air Density
Engine Air Flow	249.151	lbs air/hr	Engine Air Flow (lb/min) x 60 min/hr (lb/hr)

Conversion Factors		
1 cu ft =	7.408	gal
1 cu ft =	1728	cu in/cu ft
1 cu in =	16.3871	cc
1 gal =	3.7854	liter
1 cu ft =	28316.8	cc
1 atm =	101.325	kPa
UGC (R) =	0.287	kJ/kg °K
lbs/cu ft =	0.0624	kg/cu m

Fuel Consumption Chart

RPM	(gal/hr)
100	0.117
200	0.234
300	0.351
400	0.468
500	0.585
600	0.702
700	0.819
800	0.936
900	1.053
1000	1.170
1100	1.287
1200	1.404
1300	1.520
1400	1.637
1500	1.754
1600	1.871
1700	1.988
1800	2.105
1900	2.222
2000	2.339
2100	2.456
2200	2.573
2300	2.690
2400	2.807
2500	2.924
2600	3.041
2700	3.158
2800	3.275
2900	3.392
3000	3.509
3100	3.626
3200	3.743
3300	3.860
3400	3.977
3500	4.094
3600	4.211
3700	4.328
3800	4.445
3900	4.561
4000	4.678



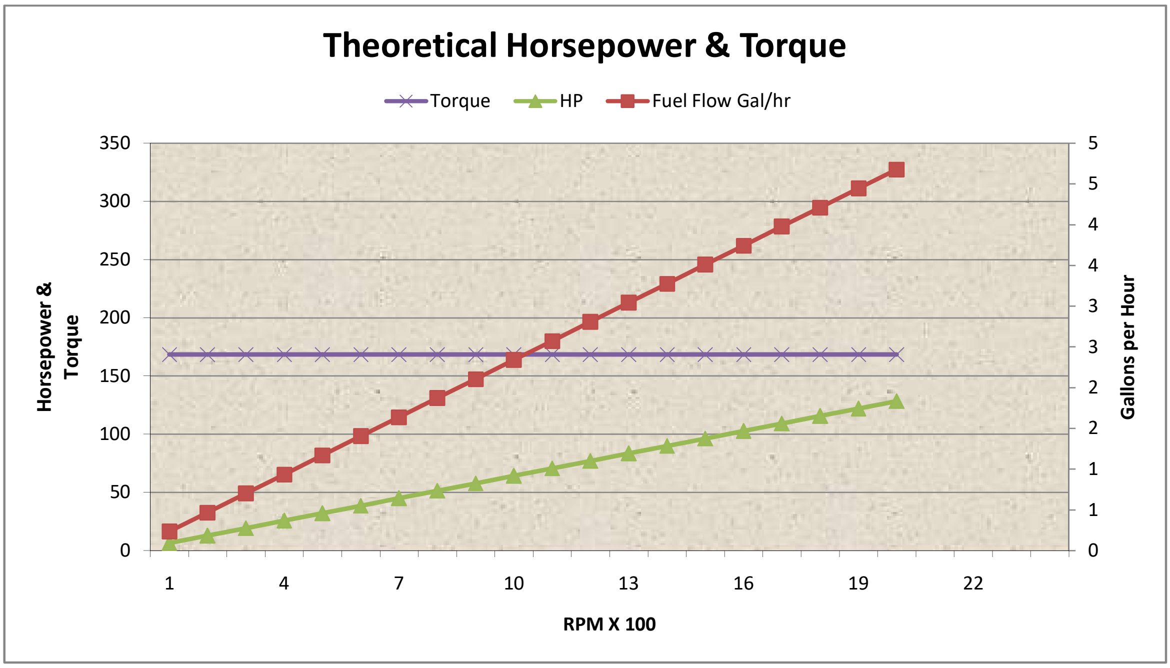
Horsepower

Description	Value	Units
Fuel Density (FD) =	6.073	lbs/gal
Fuel Heating Energy (FE) =	20,853	BTU/lb
Engine Speed (RPM) =	2,200	rev/min
Fuel Flow at Specified RPM =	2.573	gal/hr
Combustion Thermal Efficiency (TEc) =	55.080	%
HP / BTU (HPE) =	2542	HP / BTU/hr
Air to Fuel Ratio =	15	: 1
Engine Displacement =	47.549	cu in
Volumetric Efficiency (VE) =	0.85	%

Combustion Thermal Efficiency (TEc) x Fuel Flow (gph) x FD (lb/gal) x FE (BTU/lb) / HPE	**70.608**	**HP**
Torque	**168.561**	**ft-lb**

TEc/100	Fuel Flow at Specified RPM	FD	FE	HP/BTU (HPE)
0.551	2.573	6.073	20853	2542 HP/hr

RPM	Fuel Flow gal/hr	HP	Torque
200	0.234	6.419	168.561
400	0.468	12.838	168.561
600	0.702	19.257	168.561
800	0.936	25.676	168.561
1000	1.170	32.095	168.561
1200	1.404	38.514	168.561
1400	1.637	44.932	168.561
1600	1.871	51.351	168.561
1800	2.105	57.770	168.561
2000	2.339	64.189	168.561
2200	2.573	70.608	168.561
2400	2.807	77.027	168.561
2600	3.041	83.446	168.561
2800	3.275	89.865	168.561
3000	3.509	96.284	168.561
3200	3.743	102.703	168.561
3400	3.977	109.122	168.561
3600	4.211	115.541	168.561
3800	4.445	121.960	168.561
4000	4.678	128.379	168.561



Combustion

Air Standard Cycles
The air standard cycle is a cycle followed by a heat engine which uses air as the working medium. Since the air standard analysis is the simplest and most idealistic, such cycles are also called ideal cycles and the engine running on such cycles are called *ideal engines*.

In order that the analysis is made as simple as possible, certain assumptions have to be made. These assumptions result in an analysis that is far from correct for most actual combustion engine processes, but the analysis is of considerable value for indicating the upper limit of performance. The analysis is also a simple means for indicating the relative effects of principal variables of the cycle and the relative size of the apparatus.

Assumptions

1. The working medium is a perfect gas with constant specific heats and molecular weight corresponding to values at room temperature.
2. No chemical reactions occur during the cycle. The heat addition and heat rejection processes are merely heat transfer processes.
3. The processes are reversible.
4. Losses by heat transfer from the apparatus to the atmosphere are assumed to be zero in this analysis.
5. The working medium at the end of the process (cycle) is unchanged and is at the same condition as at the beginning of the process (cycle).

Using an Air Standard Cycle Analysis, estimate work per unit mass of air, thermal efficiency, combustion pressure, and cutoff ratio.

Basis of estimate:

	Value	Units
T_1 =	273	K
T_3 =	1500	K
P_1 =	1	atm
V_1 / V_2 =	8.5	**:1**
Cp =	1.010	kJ/kg °K
Cv =	0.718	kJ/kg °K
K =	1.407	ratio
RPM =	2200	rev/min
Fuel Density =	6.073	lb/gal
1 cu ft fuel =	7.408	gal

Calculated Displacement

V_1 =	47.549	cu in

Applying the Compression Ratio to the Chamber Volume

V_2 = Displacement/Compression Ratio =	5.589	cu in

then, temperature at end of compression stroke is

$T_2 = T_1 \times (V_1/V_2)^{1.4-1}$ =	278.908	K

and the combustion pressure is

$P_2 = P_1 \times (\text{compression ratio})^{1.4}$	8.691	atm

Then the cutoff ratio (COR) is

$V_3 / V_2 = T_3 / T_2$	5.378	ratio
$V_3 = T_3 / T_2 * V_2$	30.061	cu in
P3 =	1	atm
$P_4 = P_2 \times V_2 \times T_4 / (T_2 \times V_4)$	5.469369	atm

Basis of estimate (continued): Value Units

The expansion ratio is calculated as follows:

	Value	Units
$V_4 / V_3 = (V_1 / V_2)/(V_3 / V_2)$	1.582	ratio
$V_4 = (V_1 / V_2)/(V_3 / V_2) * V_3$	47.549	cu in
$T_4 = T_3 * (V_3 / V_4)^{1.4-1}$	1493.138	K

work per unit mass of air

$w = 1.005 \times (T_3 - T_2) + (1.005/1.4) \times (T_1 - T_4)$	13.100	kJ/kg

constant volume heat addition

$q_a = 1.005 \times (T_3 - T_2)$	1227.198	kJ/kg

and cycle thermal efficiency

$N_{th} = w / q_a$	1.068	%

Power to compress air P_1 to P_2

CFM (single chamber volume)	5.045	CFM
$0.2267 \times \text{Quantity cfm} \times \{[(P_2/P_1)+1]^{0.283-1}\}$	1.031	HP
$q_b = 1.005 \times (T_1 - T_4)$ =	-1226.238	
Fuel Rate (gal/hr) =	2.573	gal/hr
Fuel Rate/min=gal/hr/60xfuel density(lb/gal)	0.260	lb/min

Power Lost to Exhaust

(-1) x q_b x Fuel Rate/min/1 HP x vane height	0.683	HP

Summary:

T_1 =	273.000	P_1 =	1.000	V_1 =	47.549
T_2 =	278.908	P_2 =	8.691	V_2 =	5.589
T_3 =	1500.000	P_3 =	1.000	V_3 =	30.061
T_4 =	1493.138	P_4 =	5.469	V_4 =	47.549

Given Displacement, Calculate HP, Torque & Weight #1

NOTE: This independent spreadsheet determines HP, torque & weight based on a desired displacement.

Gasoline: Enter G Diesel: Enter D	D	Displacement (cu in)	183.407	RPM	2000	b/a ratio	1.333

Pi (π)	3.14159	Ratio, Circle circumference to Diameter
cu in/cu ft	1728	Number cu in per cu ft
min/hr	60	Number minutes per hour
Steel Density	0.286	Pounds per cu in
Aluminum Density	0.095	Pounds per cu in
Pa (lb/cu ft)	0.081	Air Density (0.0807 at STP)
EFR (f)	0.806	Equivalence Fuel Ratio (f)
SFMF (f)	0.064	Stoichiometric Fuel Mass Fraction (f)
HP / BTU (HPE)	2542	Horse Power per BTU
VE	0.85	Est Volumetric Efficiency (Typical = 0.85)
Friction	0.1	Est Friction Factor (Typical = 0.10)
Heat Loss	0.1	Est Engine Heat Loss Factor (Typical = 0.10)
Engine Loss	0.2	Est Engine Loss (pressure, efficiencies) (Typical=0.10)
Rotor Hub Radius	1	inch
Vane Quantity (#V)	12	Number Vanes
Average Vane Ext (V%)	0.500	Average Vane Extension (%)
Vane thickness (Vt)	0.250	Vane thickness (in)
End Plates	2	Quantity
End Plates Thickness (Et)	1	Thickness of End Plates (in)
Housing Thickness (Ht)	1	Thickness of Housing (in)
Compression Ratio	18.5	Combustion Ratio (Gasoline=8.5, Diesel=18.5)
BTU/Gal	137452	BTU/Gal (Gasoline=120476, Diesel=137452)
Fuel Density (FD)	6.943	Fuel Density (lb/gal) (Gasoline=6.217, Diesel=6.943)
Fuel Heat Energy (FE)	19604	Fuel Heat Energy (FE-BTU/lb) Gas=19948, Diesel=19604

SOLUTION	VALUE	DESCRIPTION
Desired Engine Type	Diesel	Diesel Engine Selected
Desired DISP (cu in)	183.407	w[πab-πr^2-#vanes x vane length x vane width x % use]
Desired RPM	2000	RPM
Desired Major/Minor Axis Ratio	1.333	Ratio b/a
Major Axis (a)	4.606	Ellipse Minor Axis & Circle Radius, a, r (in)
Minor Axis (b)	6.141	Ellipse Major Axis, b (in)
VH =	3.071	Vane Height (in) = Ellipse Minor Axis - Hub
VT =	1.535	Vane Travel (in) = Vane Height / 2
W =	9.212	Rotor Depth = 2 x Ellipse Major Axis
Housing Dia =	14.283	Housing Diameter = 2 x (Minor Axis + Housing Width)
CTE (TEc)	0.5508	VE (1-Friction Loss)x(1-Heat Loss)x(1-Engine Loss)
Mass of Air (Ma) =	14.615	lb/min
Fuel Flow Rate =	6.515	gal/hr
Approx weight (w) lb =	238.042	Approx Weight (lb)
Calculated HP @ RPM	192.148	Calculated Horsepower
Torque =	504.580	Torque (lbf·ft)

Given Displacement, Calculate HP, Torque & Weight #2

This independent spreadsheet determines HP, torque & weight based on a desired displacement.

Displacement Calculation

Convert displacement volume into cubic equation ax^3 + bx^2 + cx + d = 0
w[πab-πr^2-# vanes x vane length (b-a) x vane thickness x % effective] - disp = 0
substitutimg for w, r, b and disp
2a[πaka-πa^2-#V x (ka-a) - Vt x V%] - 183.407 = 0
expanding
2πa^3x(k-1)-2a[#Vx(ka-a)xVtxV%] - 183.407 = 0
substituting desired vane constants values
2πa^3 x (1.333 -1) - 2a^2 - [12*.5x .25 x (1.333 -1)] - 183.407
consolidating
2πa^3 x (1.333 -1) - 3a^2 x (1.333 -1)) - 183.41 = 0
6.283 x (1.333 -1) - 3a^2 x (183.407 = 0
threfore a, b, c, d coefficients of cubic equation ax^3 + bx^2 + cx + d = 0

coeff a =	6.283 x (	1.333	-1) =	2.094
coeff b =	-3.000 x (	1.333	-1) =	-1.000
coeff c =				0.000
coeff d =				-183.407

for cubic equation ax^3 + bx^2 + cx + d = 0, using the on line cubic equation calculator at:
https://www.1728.org/cubic.htm major axis a 4.606

Weight	Value	Description
Aluminum x w x [π(b+thickness)^2 - 2πab]		Aluminum x w x [π(b+thickness)^2 - 2πab]
inserting values		
lb Aluminum =	62.442	Aluminum*W*(π*(b+Ht)^2-π*a*b)
Steel x w x π r^2		
inserting v		inserting values
lb steel =	175.599	steel*w*π*a^2
total weight = Aluminum + Steel		
lb total =	238.042	lb Aluminum + lb steel

Horsepower, calculate Ma and FFR

First calculate Fuel Flow as function of Displacement and RPM
where Fuel Flow = Mass of Air (Ma)xEquivalence Fuel Ratio (f)xStoichiometric Fuel Mass Fraction (f)
and Mass of Air (Ma) = Est Volumetric Efficiency (VE) x Air Density (Pa) x Disp x RPM / (cu in/cu ft)

substituting:	Ma =	14.615	lb/min
and Fuel Flow Rate:	FFR =	0.754	lb/min
divide by FD		0.109	gal/min
divide by 60 min/hr		6.515	gal/hr

Calculate Horsepower

HP = TEc x FFR x Fuel Density (FD) x Fuel Energy (FE) / BTU/hr =	192.148
Torque = HP x 5252 / RPM =	504.580

Given HP, Calculate Torque, Displacement & Weight #1

This independent spreadsheet determines displacement, weight & torque based on a desired HP

Desired Values	Gasoline: Enter G Diesel: Enter D	D	HP	150	RPM	2000	CR	20.0	b/a ratio	1.333

Description	Value	Units
Pi	3.1415927	:1 ratio
1 Horsepower	2542	BTU/hr, aka HPE
1 Horsepower	550	ft-lb/sec
1 Horsepower	6600	in-lb/sec
Minutes per Hour	60	min/hr
1 Atmosphere	14.7	psi
Efficiency Factors & Assumptions		
Est Volumetric Efficiency *(VE)*	0.85	Est Volumetric Efficiency (Typical = 0.85)
Friction	0.1	Est Friction Factor (Typical = 0.10)
Heat Loss	0.1	Est Engine Heat Loss Factor (Typical = 0.10)
Engine Loss	0.2	Est Engine Loss (pressure, efficiencies) (Typical=0.10)
Combustion Thermal Efficiency (TEc)	0.5508	factor
Material Density	**Value**	Units
Material Factor Steel=0.286	0.286	Handbook
Material Factor Alum=0.095	0.095	Handbook
Ellipse		
Ellipse Minor Axis, a	4.606	in
Ellipse Major Axis, b	6.141	in
Rotor		
Rotor Radius, r = a	4.606	in
Rotor and vane depth (w = 2 x a)	9.212	in
Vanes		in
Number of Vanes	12	Average Vane Extension (%)
Vane thickness (Vt)	0.250	in
Vane Travel (VT = b-a)	1.535	in
Average Vane Ext (V%)	0.500	in
Outputs		
Desired Horsepower	150	HP
Torque at Given HP and RPM	393.900	lbf-ft
Displacement	183.407	cu in
Weight	238.042	lb

Given HP, Calculate Torque, Displacement & Weight #2

Calculate Displacement

Max Air Pressure = 1 atmosphere x compression ratio
P-max =
HP = Displacement x Pressure x RPM x (Est. Combustion Thermal Efficiency)
Disp = HP (ft-lb/sec) x HP/(in-lb/sec) / [P-max x RPM/(min/hr) x TEc]
Disp = 183.4067 cu in

Displacement Detail Calculation

Convert displacement volume into cubic equation ax^3 + bx^2 + cx + d = 0
w[πab-πr^2-# vanes x vane length (b-a) x vane thickness x % effective] - disp = 0
substitutimg for w, r, b and disp
2a[πaka-πa^2-#V x (ka-a) - Vt x V%] - 183.4067 = 0
expanding
2πa^3x(k-1)-2a[#Vx(ka-a)xVtxV%] - 183.4067 = 0
substituting desired vane constants values
2πa^3 x (1.333 -1) - 2a^2 - [12*.5x .25 x (1.333 -1)] - 183.407
consolidating
2πa^3 x (1.333 -1) - 3a^2 x 1.333 -1)) - 183.407 = 0
6.283 x (1.333 -1) - 3a^2 x 183.407 = 0
threfore a, b, c, d coefficients of cubic equation ax^3 + bx^2 + cx + d = 0

coeff a =	6.283 x (	1.333	-1) =	2.094
coeff b =	-3.000 x (	1.333	-1) =	-1.000
coeff c =				0.000
coeff d =				-183.407

for cubic equation ax^3 + bx^2 + cx + d = 0, use the cubic equation calculator tab.
major axis a = 4.606

Weight	Value	Description
Aluminum x w x [π(b+thickness)^2 - 2πab]		Aluminum x w x [π(b+thickness)^2 - 2πab]
inserting values		
lb Aluminum =	62.442	Aluminum*W*(π*(b+Ht)^2-π*a*b)
Steel x w x π r^2		
inserting v		inserting values
lb steel =	175.599	steel*w*π*a^2
total weight = Aluminum + Steel		
lb total =	238.042	lb Aluminum + lb steel

Cubic Equation Solution

Given cubic equation ax^3 + bx^2 + cx + d = 0 and coefficients a, b, c and d, find solution x

$$x = \sqrt[3]{\left(\frac{-b^3}{27a^3}+\frac{bc}{6a^2}-\frac{d}{2a}\right)+\sqrt{\left(\frac{-b^3}{27a^3}+\frac{bc}{6a^2}-\frac{d}{2a}\right)^2+\left(\frac{c}{3a}-\frac{b^2}{9a^2}\right)^3}}$$

$$+\sqrt[3]{\left(\frac{-b^3}{27a^3}+\frac{bc}{6a^2}-\frac{d}{2a}\right)-\sqrt{\left(\frac{-b^3}{27a^3}+\frac{bc}{6a^2}-\frac{d}{2a}\right)^2+\left(\frac{c}{3a}-\frac{b^2}{9a^2}\right)^3}}-\frac{b}{3a}$$

Here are the values of coefficients a, b, c and d for the cubic equation ax^3 + bx^2 + cx + d = 0

a =	2.094
b =	-1.000
c =	0.000
d =	-183.407

First we define a variable 'F':

F =[(3c/a) - (b²/a²)]/3 =	-0.076

Next we define a variable 'G':

G = [(2b³/a³) - (9bc/a²) + (27d/a)]	-87.595

Then we define variable 'H':

H = (G²/4) + (F³/27) =	1918.220

If H <= 0, all 3 roots are real, and we process variables I through P as follows:

First we define a variable 'I':

I = ((G²/4) - H)^{½} =

Next we define a variable 'J':

J = (I) ^{⅓} =

Then we define a variable 'K' (in radians):

K = arc cosine (- (G / 2I)) =

Next we define a variable 'L':

L = J • -1 =

Next we define a variable 'M':

M = cosine (K/3) =

Next we define a variable 'N':

N = (Square Root of 3) • sine (K/3) =

Last we define a variable 'P':

P = (b/3a) • -1 =

Solutions:

x_1 = 2j • cosine(K/3) -(b/3a) =	
x_2 = L • (M + N) + P =	
x_3 = L • (M - N) + P =	

If H > 0, there is only 1 real root, and we process variables R through U as follows:

First we define a variable 'R':

R = -(g/2) + (h)^{½} =	87.595

Next we define a variable 'S':

S = (R)^{⅓} =	4.441

Then we define a variable 'T':

T = -(g/2) - (h)^{½} =	0.000

Last we define a variable 'U':

U = (T)^{⅓} =	0.006

Solution:

x_1 = (S + U) - (b/3a)	4.606