CHAPTER 9: GAS POWER CYCLES

THERMODYNAMIC CYCLES:

- POWER CYCLES PRODUCE A NET POWER OUTPUT (ENGINES)
- REFRIGERATION CYCLES USE POWER TO TRANSFER HEAT
- GAS CYCLES: NO PHASE CHANGE
- VAPOR CYCLES: LIQUID + VAPOR
- OPEN CYCLES: THE WORKING FLUID IS RECHARGED AT THE END OF EACH CYCLE
- CLOSED CYCLES: THE WORKING FLUID IS RETURNED TO THE INITIAL STATE

CHAPTER 9 OBJECTIVES

- EVALUATE PERFORMANCE OF VARIOUS GAS POWER CYCLES UNDER SIMPLIFYING ASSUMPTIONS
- REVIEW THE OPERATION OF RECIPROCATING ENGINES

- ANALYZE CLOSED AND OPEN GAS POWER CYCLES

- ANALYZE OTTO, DIESEL, BRAYTON AND ~~TURBOJET~~ TURBOJET CYCLES USING AIR STANDARD ASSUMPTIONS

- MODEL THE FOLLOWING ENGINES USING THE IDEAL CYCLES:

ENGINE	CYCLE
SPARK-IGNITION	OTTO
COMPRESSION-IGNITION	DIESEL
GAS TURBINE (STATIONARY)	BRAYTON
GAS TURBINE (JET AIRCRAFT)	TURBO-JET

AIR-STANDARD ASSUMPTIONS

EVEN THOUGH COMBUSTION OCCURS IN ALL OF THE ENGINES, THE MAJORITY OF THE WORKING FLUID IS NITROGEN, WHICH BEHAVES LIKE AIR.

ASSUMPTIONS:

- THE WORKING FLUID IS AIR ONLY (IDEAL GAS)
- ALL PROCESSES IN THE CYCLE ARE INTERNALLY REVERSIBLE
- COMBUSTION IS MODELED AS HEAT ADDITION FROM A HEAT SOURCE
- THE EXHAUST PROCESS IS MODELED AS HEAT REJECTION TO A HEAT SINK

PROB. 9-12: AIR STANDARD CYCLE, CONSTANT C_p

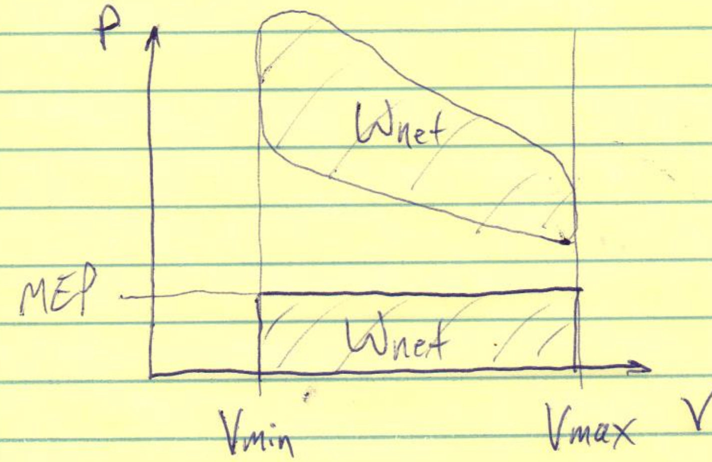
RECIPROCATING ENGINES

COMPRESSION RATIO:

$$r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}} \quad \frac{\text{BOTTOM DEAD CENTER}}{\text{TOP DEAD CENTER}}$$

MEAN EFFECTIVE PRESSURE:

IF MEP ACTED ON THE PISTON DURING THE ENTIRE POWER STROKE, IT WOULD PRODUCE THE SAME NET WORK AS THE ACTUAL CYCLE.

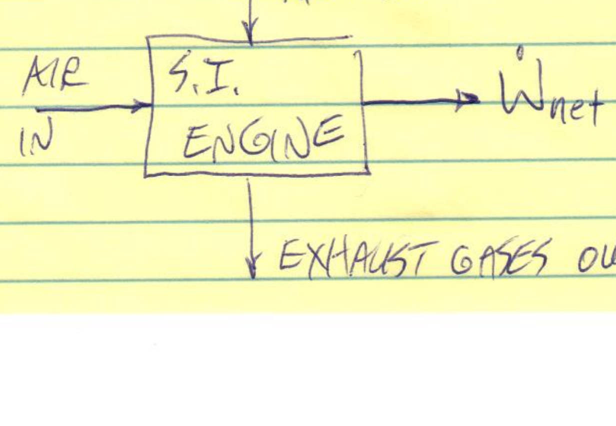


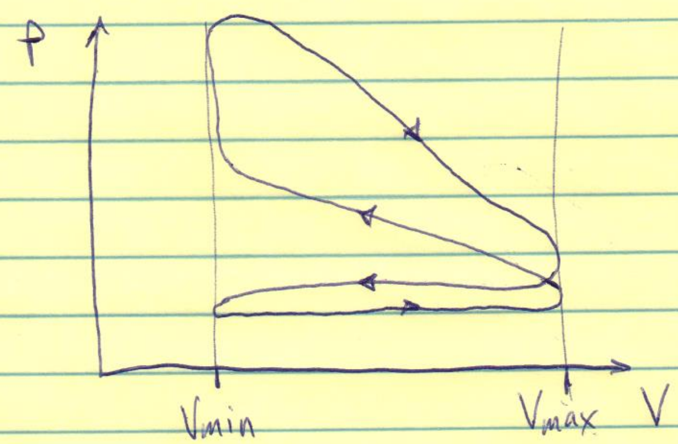
W_{net} = MEP × DISPLACEMENT VOLUME

$W_{net} = MEP(V_{max} - V_{min})$

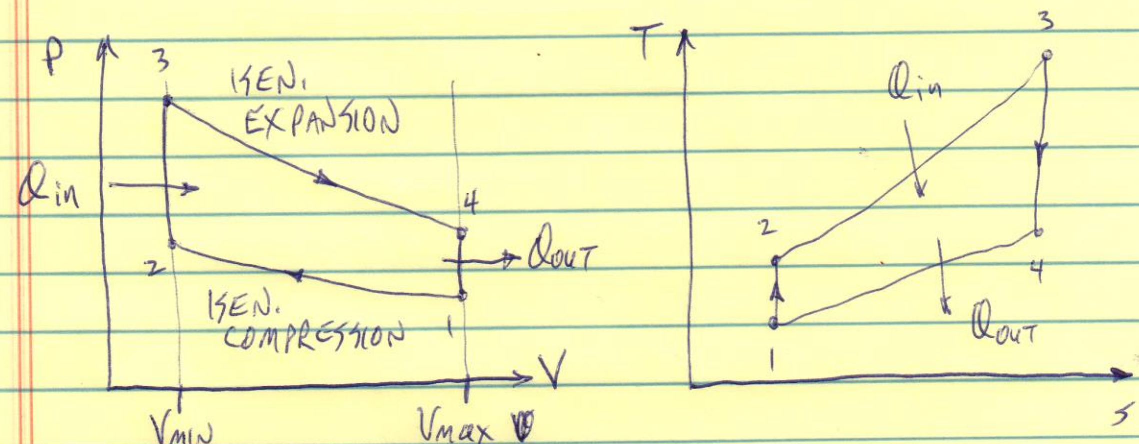
OTTO CYCLE: SPARK IGNITION ENGINES

OPEN CYCLE: REALITY





CLOSED CYCLE: SIMPLIFIED MODEL THAT WE WILL USE: OTTO CYCLE



WORK REQUIRED FOR INTAKE/EXHAUST IS NEGLECTED

OTTO CYCLE THERMAL EFFICIENCY:

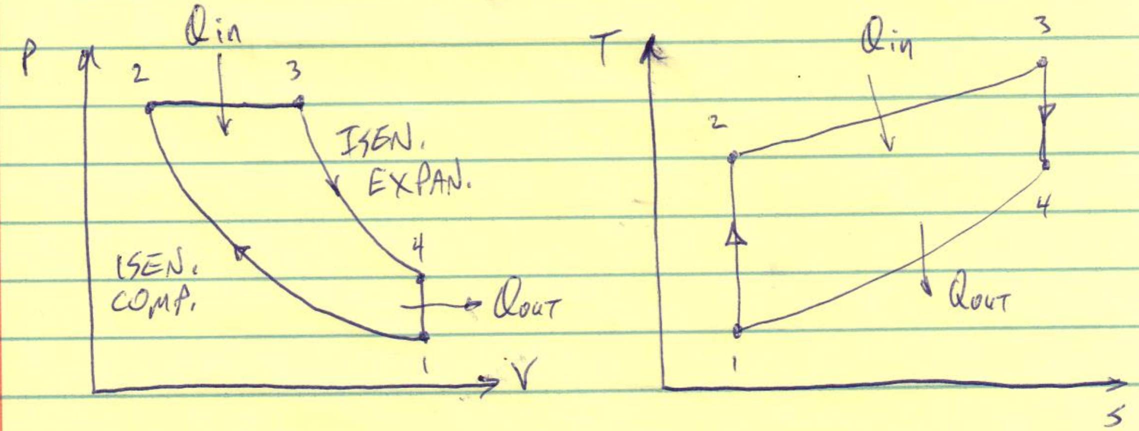
$$\eta_{TH,OTTO} = 1 - \frac{1}{r^{k-1}}, \quad k = \frac{c_p}{c_v}$$

PROB. 9-33: OTTO CYCLE, VARIABLE c_p

DIESEL CYCLE: COMPRESSION IGNITION ENGINES

OPEN CYCLE: REALITY (VERY SIMILAR TO S.I. ENGINES)

CLOSED CYCLE: DIESEL CYCLE



THE DIFFERENCE BETWEEN OTTO AND DIESEL CYCLES IS PROCESS 2 TO 3: HEAT ADDITION (COMBUSTION PROCESS)

- OTTO: CONSTANT VOLUME PROCESS

- DIESEL: CONSTANT PRESSURE PROCESS

FOR DIESEL CYCLE, THE CUTOFF RATIO IS THE RATIO OF CYLINDER VOLUMES BEFORE AND AFTER THE COMBUSTION PROCESS.

$$r_c = \frac{V_3}{V_2}$$

DIESEL CYCLE THERMAL EFFICIENCY:

$$\eta_{TH,DIESEL} = 1 - \frac{1}{r^{k-1}} \cdot \left[\frac{r_c^{k} - 1}{k(r_c - 1)} \right]$$

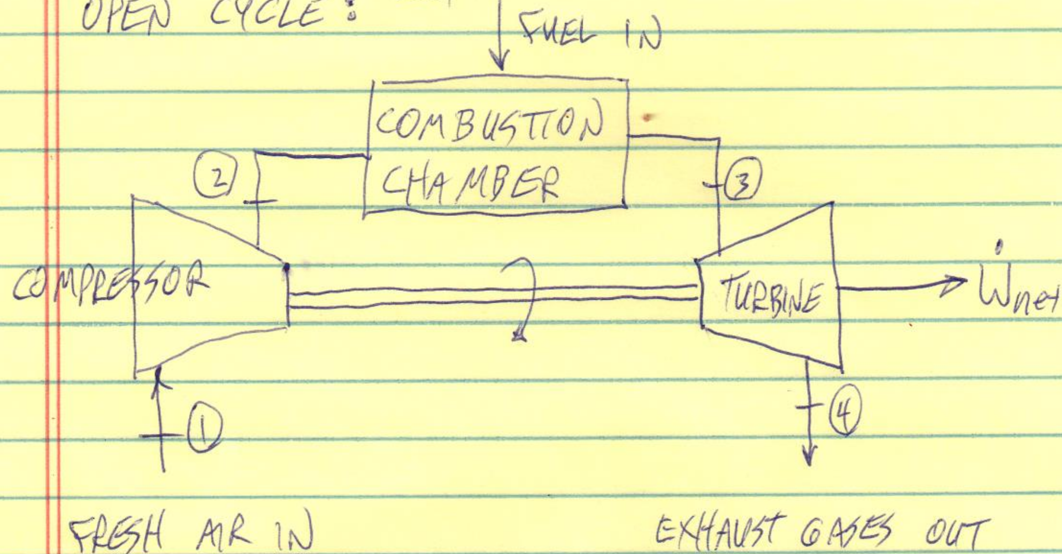
PROB. 9-46: DIESEL CYCLE, VARIABLE C_p

BRAYTON CYCLE: IDEAL CYCLE FOR GAS-TURBINE ENGINES

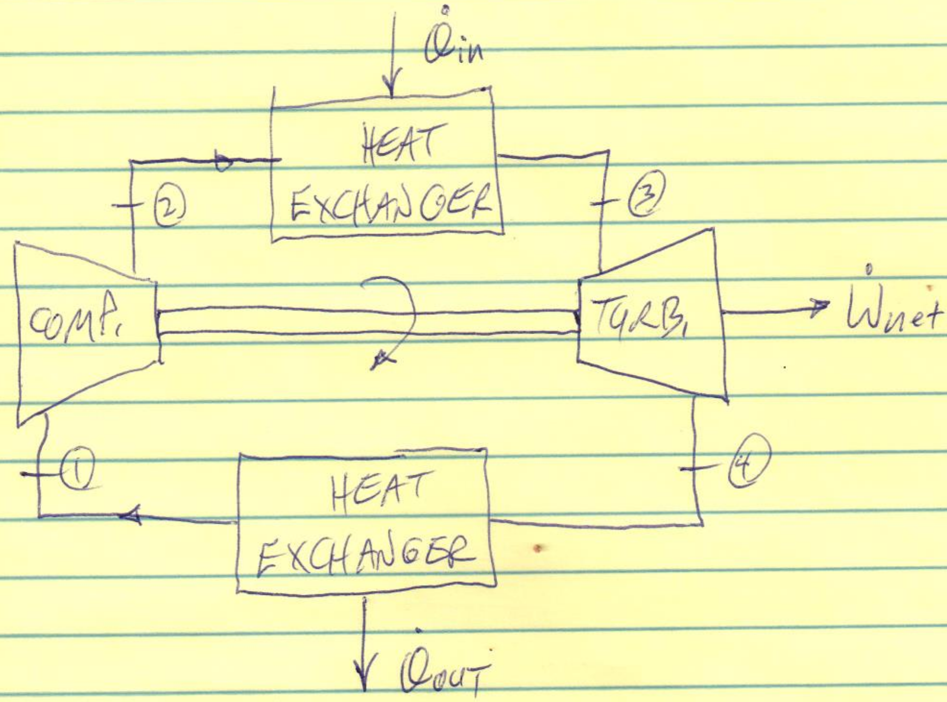
G-T ENGINES ARE USED IN POWER PLANTS AND ON BOARD SHIPS FOR ELECTRICAL POWER GENERATION, AND ON BOARD AIRCRAFT FOR PROPULSION.

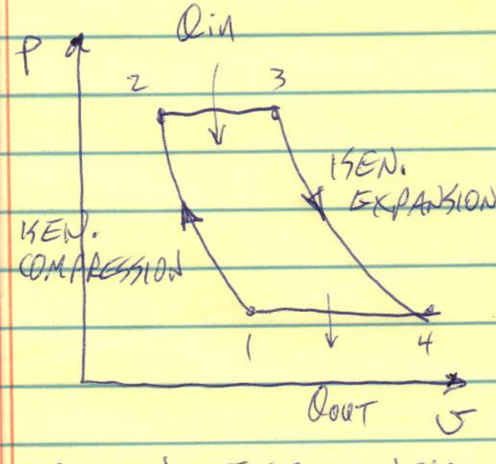
POWER GENERATION

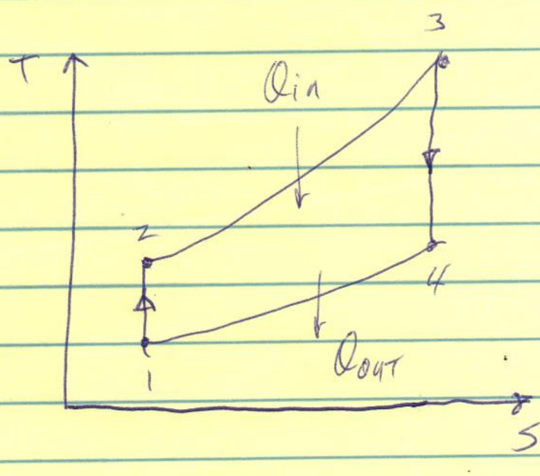
OPEN CYCLE: REALITY



CLOSED CYCLE: SIMPLIFIED MODEL THAT WE WILL USE: BRAYTON CYCLE







BRAYTON EFFICIENCY:

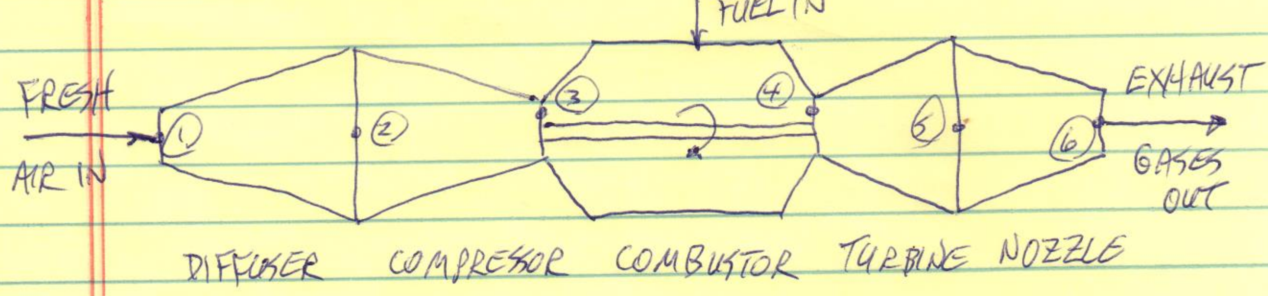
$$\eta_{TH,B} = 1 - \frac{1}{r_p^{(k-1)/k}}$$

$r_p = P_2/P_1$ = PRESSURE RATIO FIG. 9-32

PROB. 9-80E: BRAYTON CYCLE, POWER PLANT, VARIABLE C_p

AIRCRAFT PROPULSION

OPEN CYCLE : REALITY



DIFFUSER DECELERATES INCOMING AIR (STAGNATES THE FLOW, WHICH INCREASES THE PRESSURE AND TEMPERATURE)

COMPRESSOR FURTHER INCREASES PRESSURE AND TEMPERATURE

COMBUSTOR HEAT ADDITION

TURBINE GENERATES JUST ENOUGH POWER TO DRIVE THE COMPRESSOR

NOZZLE ACCELERATES THE EXHAUST GASES

THRUST (PROPULSIVE FORCE) IS GENERATED DUE TO THE CHANGE IN VELOCITY BETWEEN THE INCOMING AIR AND THE EXITING EXHAUST GASES.

NEWTON'S 2ND LAW:

$$\Sigma F = ma = m \cdot \frac{dv}{dt} = \frac{m}{dt} \cdot dv = \dot{m}(\vec{V}_e - \vec{V}_i)$$

$$THRUST = \dot{m}(\vec{V}_e - \vec{V}_i)$$

WORK = FORCE × DISTANCE

$$POWER = FORCE \times \frac{DISTANCE}{TIME} = \frac{WORK}{TIME}$$

PROPULSIVE POWER = THRUST × AIRSPEED

$$\dot{W}_p = \dot{m}(\vec{V}_e - \vec{V}_i) V_\infty$$

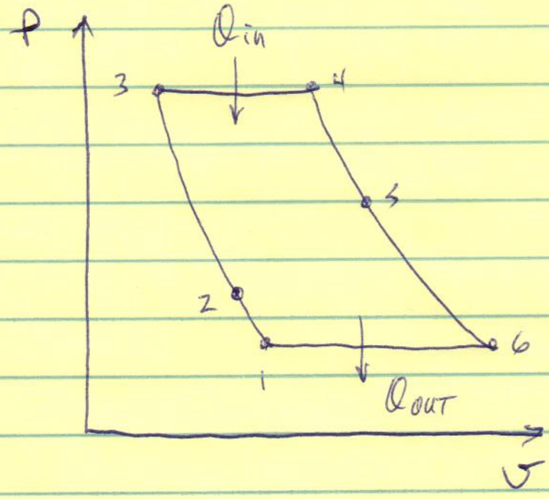
PROPULSIVE EFFICIENCY:

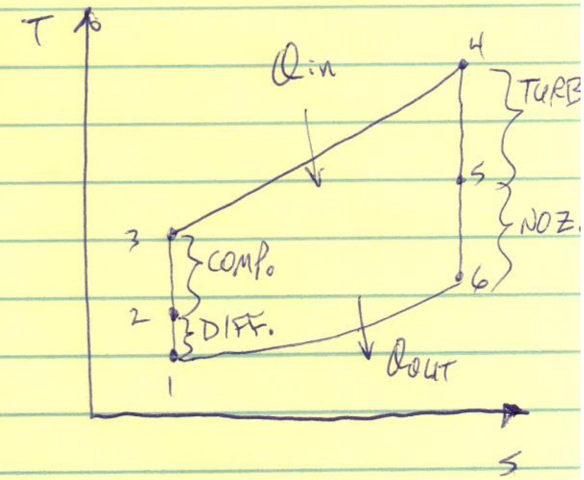
$$\eta_p = \frac{PROPULSIVE\ POWER}{ENERGY\ INPUT\ RATE} = \frac{\dot{W}_p}{\dot{Q}_{in}}$$

$$\dot{Q}_{in} = \dot{m}_{FUEL} \times FUEL\ HEATING\ VALUE$$

CLOSED CYCLE: SIMPLIFIED MODEL THAT WE WILL USE

TURBOJET CYCLE





PROB. 9-130E: BRAYTON CYCLE, TURBOJET, VARIABLE C_p

$\eta_C = 1$; $\eta_T = 1$