R.A.F. FORM 620

Royal Air Force.

NOTE BOOK
FOR
WORKSHOP & LABORATORY RECORDS.

Name .... No. ....

R.A.F. Station ....

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INTRODUCTION TO THE GAS TURBINE ENGINE

EXAMPLE. POWER AND PERFORMANCE.

A spitfire flying at a uniform speed of 300 M.P.H. THRUST must equal DRAG in order to maintain the speed. Increase the speed to 600 M.P.H DRAG increases as the square of the speed increase, and power required increases as the cube of the speed increase. The following table shows the results (assuming a propellor efficiency of 80%)

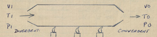
SPEED	DRAG	B.H.P.
300 M.P.H	1000 lbs	1,000
600 M.P.H	4000 lbs (2×2).	8,000 (2×2×2).

PROPELLOR ONLY ABOUT 50% EFICIENCY AT 600 M.P.H. Therefore an engine of over 12000 B.H.P would be required

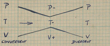
WORKING PRINCIPLES

All movement depends on Newtons Third Law of Motion which states that:- "To every action there is an opposite and equal reaction"

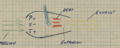
THE THERMAL DUCT



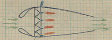
A jet engine uses air from the atmosphere as its working fluid



RAM JET



PULSE JET



NON RETURN - FLAP OR REED VALVES.

In a simple duct air enters the divegent nozzle at the front, therefore the velocity of the air decreases, pressure increases

The convergent nozzle at the rear end will have the reverse effect, By heating, the heat energy absorbed by the air is converted to kinetic energy, and the air will leave the duct at a greater velocity so creating a reactive forward force - THRUST.

The thermal duct can be still further improved by adding heat by internal combustion which also adds the products of combustion to the air mass. This is the principle of the RAM-JET.

PULSE JET

At the forward end of the duct is shown a series of non-return valves and fuel injection nozzles, Air pressure entering the duct causes the non-return valves to open and air is rammed in to mix with the fuel, as the temp is raised by combustion there is a rapid expansion and due to appropriate proportioning of the exit nozzle a rise in pressure which closes the NRU^s

The ejection of the gasses causes a depression which allows the NRU^s to open, admit a fresh charge of air and so repeat the cycle - again THRUST was the reaction to the rapid ejection of the gasses.

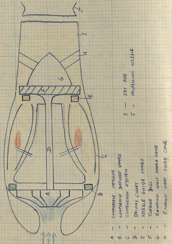
RAM JET.

The thermal duct can be still further improved by adding heat by internal combustion which also adds the products of combustion to the air mass. This is the Principle of the RAM-JET.

THE SIMPLE GAS TURBINE

APPLICATION OF PRINCIPLE

Air is drawn in slowly, compressed by compressor, fuel injected and ignited within combustion system. Gasses expanded rearwards to drive TURBINE, finally being ejected from propelling



nozzle at high velocity
Gasses have therefore been accelerated from Inlet velocity to Outlet Velocity. To do this a force has been applied it is the reaction to this force that gives the forward THRUST.

FUEL AIR MIXING.

Overall Air/Fuel RATIO of a Gas Turbine Engine is between 60 and 70 to 1 The air is mixed with the fuel in three stages

PRIMARY AIR Approximately 15% of Total Air being thoroughly mixed with the fuel initiating combustion

SECONDARY AIR Completes combustion, shapes the flame and helps starts to cool

TERTIARY AIR Cools the gasses to a figure acceptable to the turbine assembly.

N.B. Of the total air intake only about 25% is actually burnt

COMBUSTION CHAMBERS

PURPOSE To heat and accelerate the mass flow of air in a rearward direction without raising the pressure

TYPES OF COMBUSTION CHAMBER

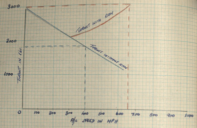
(A) (1) Independant chambers complete with flame tubes
(2) Cannular complete with flame tubes
(b) Annular with single Annular flame tube

CANNULAR AND INDEPENDENT SYSTEM.

In order to stabilize a flame created by an atomozer type of burner, flame tubes are necessary
Flame tubes carry swirl vanes, and meter the air flow into primary secondary and tertiary stages

ANNULAR SYSTEM.

Reverse flow primary air tubes are used to heat the



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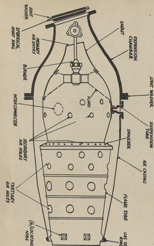


COMBUSTION CHAMBERS

mixture of air and fuel into a vapourised state
Secondary air tubes control the secondary air metering
Tertiary air is metered through annular flame tube liners

THRUST CALCULATION

The thrust obtained from a jet engine is the reaction created from accelerating the air from inlet to jet velocity, so that FORCE = MASS × ACCELERATION

$$\therefore T = \frac{W}{G} \times (V0 - V1)$$

WHERE T = THRUST
W = WT OF AIR IN lbs/SEC
G = GRAVITATIONAL FORCE (32·18)
V0 = JET OUTLET VELOCITY
V1 = JET INLET VELOCITY

STATIC THRUST = $\frac{W}{G} \times V0$ since when under these conditions NO INLET VELOCITY is being considered

Assume that Mass Air Flow is 60 lbs/sec and jet velocity is 1600 ft sec static thrust will be

$$T = \frac{60}{32 \cdot 18} \times 1600 = 3000 \text{ lbs}$$

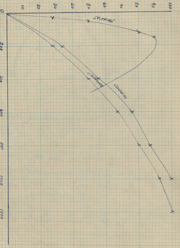
Increase the forward speed to 400 M.P.H (587 ft per/sec) Thrust will now be $T = \frac{60}{32 \cdot 18} \times (1600 - 587)$ $\frac{60 \times 1013}{32 \cdot 18} = 1890$ lbs (APROX).

It can be seen from the graph that thrust will fall as aircraft speed increases

This is true up to 300 m.P.H., but due to increasing aircraft speed, Ram pressure begins to take effect, causing an increase in mass air flow resulting in a rise in thrust

PROPULSIVE EFFICIENCY

Propulsive efficiency is a comparison between the ammount of energy put into an engine, to the ammount of



energy returned as useful work

$$\therefore PE = \frac{\text{WORK DONE IN MOVING A/C FORWARD}}{\text{AMOUNT OF KINETIC ENERGY IMPARTED TO AIRSTREAM}}$$

WORK DONE = FORCE X DISTANCE

FORCE = MASS X ACCELERATION

$= M(V0 - V1)$

DISTANCE MOVED BY A/C = V1

THEREFORE WORK DONE = $M(V0 - V1) \times V1$

$= MV1(V0 - V1)$

KINETIC ENERGY = $\frac{1}{2} MV^2$

$\therefore$ INTAKE ENERGY = $\frac{1}{2} MV1^2$

NOZZLE ENERGY = $\frac{1}{2} MV0^2$

$\therefore$ ENERGY PUT IN = $\frac{1}{2} MV0^2 - \frac{1}{2} MV\cancel{0}^2$

$$= \frac{MV0^2 - MV1^2}{2} = \frac{M(V0^2 - V1^2)}{2}$$

It will be remembered that $P.E = \frac{\text{work done}}{\text{Kinetic energy}}$

Therefore $$P.E. = \frac{MV1(V0 - V1)}{\frac{M(V0^2 - V1^2)}{2}}$$

$$= \frac{MV1(V0 - V1) \times 2}{M(V0^2 - V1^2)}$$

$$= \frac{2MV1(V0 - V1)}{M(V0 - V1)(V0 + V1)} = \frac{2V1}{V0 + V1}$$

EXAMPLES

1) AIRCRAFT AT REST

LET V0 = 1200 MPH

LET V1 = 0

$\therefore P.E. = \frac{2 \times 0}{1200 + 0} \times 100 = 0$

2/ AIRCRAFT MOVING AT 700 M.P.H.

V.I. = 700 M.P.H.

V.O = 1200 M.P.H.

$\therefore$ P.E. $\frac{2 \times 700}{1200 + 700} \times 100 = 73\%$

NOTE

The kinetic energy required to move a mass of air is obtained from burning fuel, it is interesting to note that use of the kinetic energy formula of $\frac{1}{2} MV^2$ will prove that it is more efficient to move a large mass of air slowly than a small mass of air at high velocity Thus:-

EXAMPLE 1

Let M equal 10 units
V equal 5 units

kinetic energy imparted to airstream to move a large mass of air at low velocity

$= \frac{1}{2} \times 10 \times 5^2 = 125$ UNITS.

EXAMPLE 2.

Let M equal 5 UNITS.
V equal 10 UNITS

kinetic energy imparted to airstream to move a small mass of air quickly $= \frac{1}{2} \times 5 \times 10^2 = 250$ UNITS

$\therefore$ in examples (1) the S.F.C will be lower (SPECIFIC FUEL CONSUMPTION)

SPECIFIC FUEL CONSUMPTION.

$$S.F.C = \frac{\text{TOTAL FUEL CONSUMPTION (lbs/hr)}}{\text{THRUST (lb)}}.$$

Example

THRUST = 1000 lb
FUEL CONSUMPTION = 1,300 lbs/hr

$\therefore$ S.F.C $= \frac{1,300}{1,000} = 1 \cdot 3$ lb/hr/lb THRUST.

or may be expressed as $1 \cdot 3$ lb/lb/hr

PRACTICAL EXAMPLES.

1. RA7 THRUST AT T.O = 7600 lbs

S.F.C = ·92

Therefore total consumption will be :- 7600 × ·92 = 6.900 lbs/hr
Assuming 1 gallon of fuel weighs 8 lbs consumption in gallons will be $\frac{6900}{8}$ = 862 galls

2. SAPPHIRE THRUST AT T.O = 10,500

S.F.C = ·885

Therefore total fuel consumption will be 10,500 × 885 = 9292·5 lbs/hr
Again assuming 1 gallon weighs 8 lbs consumption in gallons will be :- $\frac{9292 \cdot 5}{8}$ = 1161·5 galls/hr

EJECTOR SEATS.

MK 2E EJECTOR SEAT

OPERATION

a. Pilot pulls blind and removes main sear
b. Seat moves up, withdrawing sears from drogue gun and time release unit
c. Drogue gun fires, drogue stabilizes and decelerates seat
d. 5 seconds after reaching 10,000 ft
   1. The harness is released
   2. The drogue scissors open
e. The drogue streams the parachute which pulls the pilot from the seat

SAFETY PRECAUTIONS.

BEFORE ENTERING THE COCKPIT

Ensure safety pin is in the blind restraining strap

WHEN WORKING IN THE COCKPIT.

a Transfer safety pin to the hole in main sear
  Leave cable connected

b Remove drogue gun static link pin from bracket
  on the rail

c Insert pin in the drogue gun safety hole

N.B. The precautions applicable to a particular A/C are contained in Ground Handling Notes of Vol 1 Always consult these before working on a strange A/C

MK 3 SEAT

The seat has 3 guns:—

1 Main Gun
2 Drogue Gun
3 Canopy Jettison Gun

Safety Precautions

Any seat having a red disc with 3 pins attached

DISC PINS.

1 Seat Gun A large pin is inserted in the gun sear
2 Canopy Gun A large pin is inserted in the gun sear

The third (smaller) pin is for arming and disarming purposes only

3 Drogue Gun Remove pip pin from the rail bracket, and insert in the safety hole of the gun

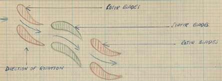


FIG (1)

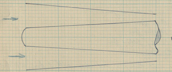


FIG 2(a)

AVON Continuous reduction in cross-sectional area results in poor matching of early and late stages efficiencies at low R.P.M necessitating the need for bleed valves

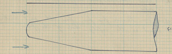


FIG 2(b)

SAPPHIRE The parallel rear section results in better stage efficiency matching thus bleed valves are not required. However more stages or higher R.P.M are necessary to give a given compression RATIO.

CENTRIFUGAL AND AXIAL FLOW COMPRESSORS

Compressors.

May be sub-divided into two main forms

a Centrifugal
b Axial flow

1 **Centrifugal Compressors**

Types of Impeller
a Single Sided
b Double Sided

2 **Axial Flow Compressors.**

a A number of discs around which are mounted aerofoil section blades, decreasing in length from front to rear. Cross section airflow through the blade increases (DIVERGING) thus increasing pressure.

b Each row of rotating blades (ROTOR) separated by a row of static blades, the (STATOR) blades, are also of aerofoil section with a divergent setting, giving a further increase in pressure with a drop in velocity. Additionally they guide the airflow on to the next stage Rotor blades at the correct angle of attack
Front stator blades may be shrouded (Gas seal and anti-flutter)

c The ammount of pressure rise in rotating, and stator blades depends on design. In the Avon for example 60% of total pressure is obtained from the rotors and 40% from the stators

d **Constant axial flow Velocity**

A design requirement is maintained by progressive reduction in overall gas flow cross-sectional area with resultant additional increase in Pressure, and Temperature.

e Each stage works at a pressure ratio of approx 1·1 to 1·2 Pressure ratios may be increased by adding more stages (within limits).

DIRECTION OF

AVON

R.P.M

SAPPHIRE

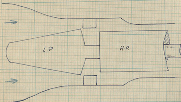


FIG (2C)

OLYMPUS. Two compressors running independantly of each other enable early and late stage efficiency problems to be avoided resulting in higher compression ratio to be achieved

F. Ideal curves for pressure, and velocity should show a progressive build up in pressure, and a variation, but

pressure

all increase

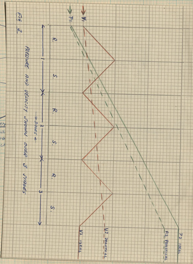
rcome by

bleed valves

3. Complex and expensive to produce.

4. Only efficient at specific R.P.M.

5. Prone to damage.



E. Ideal curves for pressure, and velocity should show a progressive build up in pressure, and a variation, but little increase in velocity. In practice however pressure rise falls short of ideal and there is a small increase in velocity (FIG 3).

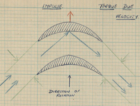
G. Compressor stall at starting, and low R.P.M overcome by the use of variable incidence guide vanes, and bleed valves

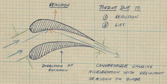
Advantages of a Centrifugal Compressor.
1. Relatively cheap to produce.
2. Robust construction.
3. Will accept icing conditions.
4. Surge not critical.
5. Will accept "RAM" effect.

Disadvantages of Centrifugal Compressor
1. Capacity limited by tip speed · 9 MACH.
2. MAX COMPRESSION RATIO 4.5 to 1.
3. Severe directional changes of air-flow.
4. Engine diameter too large.
5. High Specific Fuel Consumption

Advantages of Axial Flow Compressor.
1. High Compression Ratio 7 to 8 to 1.
2. Low specific fuel consumption.
3. Maintains straight gas flow.
4. Percentage of Power loss returned as Axial Thrust.
5. Small Frontal Area.

Disadvantages of Axial Flow Compressor.
1. Critical to surge characteristics.
2. Slow to accelerate
3. Complex and expensive to produce.
4. Only efficient at specific R.P.M
5. Prone to damage.





Development of Turbine Blade Design.

Construction

Two independant designs are incorporated in each blade

a Impulse blade design
b Reaction blade design

Impulse Design. Requires a high velocity jet to impart torque reaction to a turbine wheel. No pressure drop is felt through the blade. Design incorporated in the blade root section. Max R.P.M is reached when tip speed equals gas velocity

Re-action Design. Reaction design makes use of gas pressure. The aerofoil shape produces slight torque. The trailing edge convergence accelerates the gas flow away from the blades. The reaction imparts torque to the turbine

Metallurgical Requirements

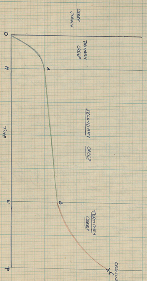
Turbine Material Requirements

In the turbine it is the moving blade which is subject to more stress. Not only must it operate at high temperature (700 - 800°c) but it must withstand a tensile stress up to 15 tons □" imposed by rotational speed. Therefore the qualities required of a turbine blade are exacting and are as follows:-

1. Oxidization and corrosion resistant
2. High creep resistance
3. Fatigue Resistance
4. Damping Capacity
5. Ductility

(1) Oxidation and Corrosion Resistant

Corrosion by the products of combustion may itself govern the life of a component and will accelerate



TYPICAL CREEP STRAIN CURVE

"creep" and "Fatigue Failure" A high resistance to Oxidation and Corrosion under conditions of repeated heating and cooling is of major importance. Nickel Chrome alloys (NIMONICS) form a strong, closely adherent oxide which protects them from progressive attack due to oxidation and corrosion.

(2) High Creep Resistance

The main effect of stress at high operating temps is the continuous deformation that takes place in the course of time. This is commonly referred to as Creep Strain.

CREEP STRAIN Permanent deformation of a material caused by a load imposed for a period of time. It is a function of LOAD, TEMPERATURE AND TIME. Stresses giving rise to such continuous deformation will after eventually lead to failure of a part by change of dimensions, if not by failure by fracture

A typical "CREEP" curve shows that the course of deformation with time is divided into three parts.

(a) PRIMARY CREEP OA in which stage the creep rate increases rapidly but at a decreasing rate

(b) SECONDARY CREEP AB The stage covering the major portion in the life of the component when the creep rate is decreasing slowly or is substantially constant

(c) TERTIARY CREEP BC The third stage in which the rate of "creep" is rapidly increasing leading to eventual fracture

LIMITATIONS Operational limitations should not be exceeded as a rise in temp of approx 100°C above operating conditions will cause almost immediate failure. Components subjected to overheating or stress even for a short time must be carefully inspected

Evidence of undue creep may be shown by
(a) Decrease in Blade Tip clearance below limits
(b) Mottling of Blades
(c) Waisting of section
(d) Cracks in leading or Trailing Edges.

3. Fatigue Resistance. In addition to the steady stresses imposed on a turbine blade there is a fluctuating bending stress. In practice the stress conditions on a turbine blade are centrifugal plus gas bending stresses, with bending and torsional oscillations. This necessitates the greatest care in the finishing of the blade surfaces, particularly leading and trailing edges.

4. Damping Capacity. The capacity to damp out vibrations by virtue of its internal molecular friction

5. Ductility. A property which varies with loading conditions, and time. Loss of ductility with time indicates that fracture may occur suddenly

MANUFACTURE.

a. Machining from Bar
b. Forging
c. Casting

Turbine blades manufactured from Nimonic Alloys 80, 80A, 90 and 95

80 and 80A 80% NICKEL 20% CHROMIUM PLUS TITANIUM AND ALUMINIUM

90 and 95 62% NICKEL 20% CHROMIUM 18% COBALT PLUS TITANIUM AND ALUMINIUM

COBALT raises the operating temperature approx 100°C.

TURBINE
ROTOR DISCS (Austenitic or FERRITIC Steel). Disc subjected to heavy stresses, operating temps lower at the centre than at the rim resulting in radial temperature differences causing thermal expansion stresses. These stresses are super-imposed on those arising from the speed of rotation (centrifugal force) tending to burst the disc. Centrifugal force stresses vary as the square of the velocity.

NOZZLE GUIDE VANES NIMONIC 75 is used in the form of Rolled forged or Cast guide vanes. A frequent source of failure of these components is cracking or buckling due to repeated thermal stress arising from steep temperature gradient, on starting the engine.

FLAME TUBES NIMONIC 75 produced in sheet form, extensively used for flame tubes and combustion chambers. The high performance of this alloy is due to a combination of properties, high creep, and fatigue strength at operating temperatures, and good resistance to oxidation and corrosion. Low coefficient of expansion an advantage in reducing thermal stresses and distortions. High ductility enabling hand beating spinning deep drawing, pressing or rolling to be used during manufacture.

DEVELOPMENT

TWIN SPOOL G.T.

DESCRIPTION Consists of two rotating assemblies, high and low pressure supported on concentric shafts. The front or L.P. compressor is driven by the rear or low pressure turbine and the rear or H.P. compressor is driven by the front or H.P. turbine.

ADVANTAGES
1. Higher compression ratio giving greater power and thus a lower or better S.F.C
2. Easier starting
3. Quick surge free acceleration.
4. Greater power at altitude

EXAMPLE BRISTOL OLYMPUS
12,000 lbs thrust S.F.C ·7

BY-PASS G.T.

DESCRIPTION Twin spool lay-out, after passing the L.P. compressor, the air splits into two flows. One of these continues on through the H.P. compressor combustion chambers and turbines while the other passes through a duct surrounding the engine. This by-pass air rejoins the gas stream somewhere aft of the turbines and results in a combined air flow of comparatively large mass passing at low velocity to the atmosphere

ADVANTAGES
1. Higher propulsive efficiency due to slower cooler jet efflux
2. Lower S.F.C.
3. Higher thermal efficiency
4. Reduced fire risks
5. Lends itself to re-heat
6. It is a lighter engine.
7. IT IS A QUIETER ENGINE

EXAMPLE R.R. CONWAY
STATIC THRUST 13,000 lb
DIAMETER 41·5 ins (SAME AS RA 28)

DUCTED FAN G.T.

DESCRIPTION. Single shaft layout, blades of turbine shrouded, blade extension from shroud project and run in a duct surrounding rear of engine. Air passing through the duct is caught up and accelerated by the blade extensions in a manner similar to a propellor. As in the by-pass G.T. a combined flow of greater mass and lower velocity finally passes to atmosphere

ADVANTAGES. AS FOR CONWAY.

EXAMPLE. METRO-VICK F/2/3

This engine was abandoned due to failure to eliminate blade extension troubles

COMPARISON OF PROPULSIVE EFFICIENCIES.

(PURE TURBO-JET AND PROPELLOR).

(a) From the graph it can be seen that the propellor reaches its peak propulsive efficiency at approx 300 M.P.H. but as the forward speed increases, the efficiency falls.

(b) The pure turbo-jet is only approx 45% efficient at 300 M.P.H but as the forward speed increases so does the P.E.

(C) Although rising, the P.E of the jet is still less than that of the propellor at speeds below 550 M.P.H Therefore the S.F.C is higher due mainly to the heat wasted in the high velocity jet

(d) The pure turbo jet is converted into a turbo-prop engine by using the gas energy to drive a propellor. About 80% of the gas energy is used in this manner the remainder providing a small propulsive thrust, termed residual thrust.

(e) Thus by using most of the gas energy to drive a propellor and not as a high velocity jet, the overall propulsive efficiency of the engine is greatly improved and so of course, must the S.F.C.

(F) The turbo-prop engine is ideally suited for A/C whose top speed does not exceed 500 M.P.H. and also where economy is important (RANGE).

(G) Thus the advantages of the pure gas turbine, ie good power weight ratio, smooth running and absence of vibration together with ease of servicing are retained, but of course the engine will be a little more complex.

TURBO-PROP ENGINES.

DIRECT COUPLED TURBO-PROP

DESCRIPTION The turbine drives the compressor, and the compressor, VIA a suitable reduction gear, drives the propeller

DISADVANTAGES

1. Special fine pitch on propeller is required to facilitate starting
2. Complex interconnection of engine and prop controls required
3. Compressor may become unstable with sudden changes of load due to attitude of A/C

EXAMPLES DART, ELAND, MAMBA, PYTHON

FREE TURBINE TURBO-PROP

DESCRIPTION The propeller and compressor are mounted on seperate shafts, each driven by its own turbine

ADVANTAGES.

1. Easier starting
2. No need for complex interconnection of controls
3. More flexible in operation

(4) Each section can operate at its optimum condition giving a good S.F.C.

DISADVANTAGES. Danger of turbine running wild in the event of reduction gear failure

EXAMPLE Bristol Proteus.

COMPOUNDED TURBO - PROP

Twin - spool layout, the front H.P turbine driving the rear H.P. compressor. The propeller reduction gear and low Pres compressor is driven by the rear low pressure turbine

ADVANTAGES As for twin spool, plus the improved P.E and S.F.C of a propeller within a given speed range

EXAMPLES R.R. TYNE
BRISTOL ORION

POWER OUTPUT OF TURBO - PROPS.

Expressed as shaft horse - power plus residual thrust or equivalent shaft horse - power

$$E.S.H.P = S.H.P + \text{RESIDUAL THRUST}$$

STATIC CONDITIONS

$$E.S.H.P = S.H.P + \frac{\text{RESIDUAL THRUST}}{2 \cdot 6}$$

EXAMPLE

Let $S.H.P = 2{,}500$

Residual thrust $= 850$ lbs.

$$E.S.H.P \quad 2500 + \frac{850}{2 \cdot 6} = 2500 + 326 = 2826$$

FLIGHT CONDITIONS

$$E.S.H.P = S.H.P + \frac{T \times V}{375}$$

WHERE T = RESIDUAL THRUST AND V = A/c SPEED IN M.P.H.

EXAMPLE Let $S.H.P = 3750$

$V = 400$ M.P.H.

$T = 50$ lb

$$= E.S.H.P = 3750 + \frac{50 \times 400}{375} = 3750 + 53 = 3803$$

FUELS.

SOLIDS – Coal – wood – and peat
LIQUIDS Kerosine, gasoline, and alchohol
GASSES Cal-gas methane butane etc.

CRUDE OIL A complex mixture of hydro-carbons
Hydro-carbons are divided into two general classes
1. SATURATED.
2. UN-SATURATED

NOTE A saturated hydro carbon is one having **no** free bonds or hooks

An unsaturated hydro-carbon is one where one or more bonds or hooks are free ie not attached to the bonds of other molecules

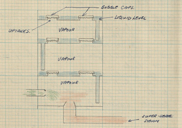
EXAMPLES **ETHYLENE** $C_2 H_4$  UNSATURATED

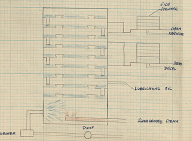
ETHANE $C_2 H_6$  SATURATED.

Another sytem of dividing or classyfying hydro-carbons is as follows.

1. **AROMATICS** (UNSATURATED).
   EXAMPLES BENZENE
   TOLUENE
   XYLENE
2. **NAPTHENES** (SATURATED)
3. **PARAFFINS** (SATURATED). These have a general formula $C_n H_{2n+2}$ where n = a whole number
   E.G. $C_n H_{2n+2} = C_{16} H_{34}$ = HEXADECANE i.e VASELINE
4. **OLEFINES** (UNSATURATED).
   These also have a general formula $C_n H_{2n}$ where n = a whole number
   E.G. Where $N = 2$ $C_2 H_4$ = ETHYLENE

FRACTIONATING COLUMN (DIAGRAMATIC).





DISTILLATION

The process by which a liquid is changed to a vapour by the application of heat and then changed back to a liquid by cooling

FRACTIONATING COLUMN

DESCRIPTION Consists of a cylindrical tower fitted with a large number of trays. Super heated steam is introduced at the bottom of the column and heated crude oil enters a little higher up the column. Liquid oil in falling meets the super-heated steam, is vapourised and the lighter fractions rise up the column through the vapour uptakes. As the vapour rise's it cools and a certain ammount condenses in each tray until the tray is full up to the level of the overflow.

Each tray is a little cooler than the one below it, therefore the higher up the colum the lighter will be the fractions condensing in each successive tray.

FLASH DISTILLATION Crude oil, heated under pressure passes into the fractioning column. Due to the reduction in pressure together with the heat of the superheated steam the oil vapourises instantaneously from then on the process proceeds as before.

SIDE - STRIPPERS

In each tray a certain ammount of liquid will condense out which has a lower boiling point than the bulk of the liquid in that tray. Liquid is drawn into a selected tray or trays in the main column into an auxiliary column termed a "side - stripper". The lighter components are boiled off and so tend to narrow the boiling range in each tray of the side-strippers. Any vapour failing to condence is returned to the main tower. By the use of side-strippers, streams of Kerosine Distillate and Diesel Oil can be obtained from the plant without further distillation

REID VAPOUR PRESSURE

The absolute pressure at which fuel heated to 100°F begins to boil

EXAMPLES AVGAS AND AVTAG 4 lbs □"
AVTUR ·1 ⅜ lbs □"

AVIATION KEROSINE

BRITISH SPECIFICATION D ENG R.D. 2482 – AVTUR
AMERICAN SPECIFICATION. MIL 5616 – J.P. 1

WIDE CUT FUELS.
BRITISH SPECIFICATION D ENG R.D. 2486 – AVTAG
AMERICAN SPECIFICATION. MIL. F. 5624 A – JP3 – JP4.

NOTE Corresponding fuels for Naval Aircraft use must have good storage qualities plus a high flash point
NAVAL KEROSINE – BRITISH – AVCAT.
AMERICAN 7914 J.P.5.

Due to poor availability of J.P.1, 6% only from a barrel of crude oil J.P.3 was specified 55% from a barrel of oil. J.P.3 had thedisadvantage of high vapour pressure causing loss of fuel and vapour locks in fuel systems. This was caused by taking a too wide "cut". The "cut" was reduced resulting in obtaining 30% per barrel and this provided a more satisfactory fuel J.P. 4.

GENERAL REQUIREMENTS OF A TURBINE FUEL

1. PUMPABILITY. Chiefly determined by viscosity, although ~~a~~ ~~Sdeu~~ a/c fuels have a low viscosity it will rise with a fall in temp and ice crystals may form causing blockage of filters

SOLUBILITY Water solvibility of a fuel increases with the decrease in molecular weight of the fuel. Water solubility increases also if the aromatic content of the fuel is increased.

DEPOSITION The critical low temperature of aviation turbine fuels is that at which deposition of solids takes place. with aircraft fuels it is usual to specify what is known as the "cloud point" temperature and this denotes that above that temp the fuel will not be un-pumbable because of increased viscosity

NOTE The definition of "cloud-point" is that temperature at which waxy solids etc are deposited from solution as the fuel is chilled

Another term which is associated with the same subject is "pour-point", this term being defined as that temperature at which the fuel will not pour readily under prescribed conditions

With distillates heavier than Kerosine the "pour point" is too high for use in A/c fuel systems at low temperature

2. Ease of starting Depends on the quality of the fuel in two ways

   1. VOLATILITY This is important particularly at starting temperatures.
   2. VISCOSITY The degree of Atomozation obtained depends on the viscosity of the fuel as well

as the design of the atomiser

(3) <u>HIGH CALORIFIC VALUE</u>. The heat of combustion of a fuel is the ammount of heat which a quantity of fuel produces on combustion

∴ Heat of combustion depends on the calorific value of the fuel. With hydro-carbons, the calorific value is usually related to the specific gravity.

<u>HEAT OF COMBUSTION</u>

FUEL	B.T.U.s PER lb	B.T.U.s PER GALLON	SPECIFIC GRAVITY
AVTUR	18,560	150,400	·816
AVTAG	18,700	144,000	·770
AVGAS	18,940	136,000	·720

It can be seen from these examples that as the specific gravity decreases there is a corresponding decrease in the heat of combustion per <u>unit volume</u> but an <u>increase</u> in heat of combustion <u>per unit weight</u>

Therefore fuel of high specific gravity is desirable for use in A/c in which fuel volume for given range is important ie fighters

For a/c in which fuel weight for given range is important fuel of low specific gravity is desirable ie BOMBERS.

(4) <u>CORROSIVE PROPERTIES</u>. The tendency of a fuel to corrode the components of a fuel system depends on—

(1) Moisture content
(2) Corrosive substances notably sulphur compounds

5. **FIRE HAZARDS** Three main hazards

(1) The spillage of fuel on a surface with subsequent ignition by a spark or by contact with red hot exhaust pipes etc,

(2) Spilling of fuel on a surface sufficiently hot enough to cause spontaneous combustion or self ignition

NOTE. SPONTANEOUS IGNITION TEMPERATURE (S I T)

Defined as the temperature to which a substance must be heated before it spontaneously ignites in the presence of air or oxygen without outside source of ignition.

EXAMPLES. AVIATION GASOLINE — S.I.T. 725°C
KEROSINE — S.I.T 625°C
AVIATION LUBRICATING OIL — S.I.T 325°C

(3) The existence of inflamable vapour or explosive mixture in the A/c fuel tank.

TEMPERATURE LIMITS OF INFLAMABILITY

	GROUND LEVEL		30,000 FT	
	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT
GASOLINE 100/130	-10	-42	-33°C	-57°C
POOL BURNING OIL	90°C	43°C	57°C	20°C

FUEL TANK PRESSURISATION

PURPOSE To reduce loss of fuel by boiling, over the full altitude range, also to prevent damage or collapse of fuel tanks and to limit fire hazards.

REQUIREMENTS A typical pressurisation system requires a predetermined nitrogen pressure, (or air pressure when nitrogen supplies are exhausted), to be maintained within the fuel tank, throughout the altitude range e.g. In the Vulcan System a pressure difference of between 2.4 and a Max of 3 lbs □" is maintained

COMPONENTS

1) FILTER RESTRICTOR A unit embodying a filter element, It has one inlet from the compressor and two outlets ie a direct line to the pressure reducing valve, and a restricted outlet going to the air/gas valve and the master control valve.

2 REDUCING VALVE Designed to provide a servo pressure that will always be 12 lbs □" above ambient air pressure

Consists of an annular bellows controlling the air delivery (from compressor) via a needle valve and seating. The inner annulus or space formed by the two bellows is subjected to ambient air pressure, while the outsides of the bellows are subjected to metered air pressure. The bellows has a "spring" value of 12 lbs □", and so ensures that the metered or servo pressure provided will always be 12 lbs □" in excess of ambient air pressure.

EMERGENCY RELIEF VALVE In the event of bellows failure dangerously high pressure is prevented by the provision of a spring loaded plate valve which opens if and when the metered pressure reaches 12.5 lbs □"

3. AIR GAS VALVE Permits delivery of air + nitrogen to the tanks

CONSTRUCTION It comprises two diaphragm operated valves

(a) The AIR VALVE which is a disc valve lightly spring loaded to the closed position and is operated by compressor air as it flows through. The valve can be held closed by a controlling diaphragm actuated by restricted P2 Pressure (see notes on Filter restrictor).

(b) The nitrogen valve which is a small spring loaded plate valve, held closed by spring pressure and nitrogen pressure. A pivotted lever operated by another diaphragm can open the gas valve when a servo pressure of 12 lbs □" is applied to the diaphragm (see notes on REDUCING VALVE).

4. VENT VALVE

PURPOSE To relieve the fuel tank of both positive and negative pressures

E.G. VULCAN POSITIVE P.D. ALLOWED + 3 lbs □"
NEGATIVE P.D ALLOWED − 0.1 lbs □"

The main vent valve seat is fitted to the end of a bellows assembly which forms an extendable inner chamber. The valve is dependent on servo pressure (12 lbs □") being applied internally to the extendable inner chamber. An internal spring ensures that the valve will be open when no servo pressure is applied. The servo valve extends the bellows and forces valve onto it's seat. Provision is made for emergency inward and outward venting.

5 MASTER CONTROL VALVE

To maintain a pre-determined pressure difference (P/D) between the fuel tanks and the outside atmosphere over the whole altitude range of the A/C.

CONSTRUCTION Consists of a spring loaded diaphragm in balance subject to fuel tank pressure on the one side and atmospheric pressure on the other, attached to centre of diaphragm is a landed spindle working within the bore of the unit. P.D' will move the diaphragm and position the landed spindle so as to control both the servo and restricted P 2 pressures used to operate the gas and vent valve and also the air valve.

MCV OPERATION

1. STATIC CONDITION i.e. Engine not running
   (a) MASTER CONTROL VALVE.
      1. VENT valve servo pressure port to atmosphere CLOSED
      2. Air valve restricted P 2 port to atmosphere open
      3. Nitrogen valve servo pressure port to atmosphere CLOSED
   (b) AIR VALVE - Closed (spring tension)
   (c) NITROGEN VALVE - CLOSED (spring pressure & gas pressure)
   (d) VENT VALVE - OPEN (internal spring)
   (e) REDUCING VALVE - OPEN

2. STARTING UP
Position of master control valve will on engine being started
   (a) Allow air valve to open and admit air pressure to tank
   (b) Cause vent valve to close (servo press)
   (c) Allow nitrogen valve to open (servo press).

3. PRESSURE BALANCE As the pressure in the tank starts to build up, The M.C.V diaphragm will react to the increased tank pressure and will move the landed spindle so that when P.D has reached 2.2 lbs □" the air valve is caused to close.

As the nitrogen continues to flow in the press difference will continue to rise and when it reaches 2.4 lbs □" the diaphragm will move the landed spindle still further in the same direction to <u>close</u> the nitrogen valve

(4) <u>TAXYING</u>. (CONTINUOUS RUNNING)

During taxying fuel would be drawn from the tanks and P.D would fall <u>below</u> 2.4 lbs □"

M.C.V will therefore move to

<u>a</u> Allow nitrogen to enter to restore P/D

<u>b</u> If fuel consumption was extremely rapid, it would also allow air valve to open if P.D fell below 2.2 lbs □"

(5) <u>CLIMBING</u> As <u>ambient</u> pressure falls off during the climb, the P/D will <u>increase</u>. If the rate of climb is extremely rapid, the M.C.V in addition to closing off both air and gas valves will move the landed spindle still further and cause the vent valve to <u>open</u>. This however will only occur if P/D exceeds 3 lbs □"

(6) <u>CONSTANT ALTITUDE</u>. At constant altitude, the M.C.V will operate nitrogen valve to maintain a P/D of 2.4 lbs □" as fuel is used up

(7) <u>PROGRESSIVE DESCENT</u> As the P/D falls below the required figure due to ambient pressure <u>increase</u> the M.C.V. will (a) cause nitrogen valve to open at a pressure of between 2.2 + 2.4 lbs □" (b) If due to rate of descent, the ~~p~~ P/D continues to fall the M.C.V will cause air valve to open also This will occur if P/D falls below 2.2 lbs □"

(8) <u>STEEP DIVE</u> During a steep dive, the ambient pressure builds up rapidly and the M.C.V causes both gas and air valves to open to pressurise tank. If however, the <u>build up</u>

of ambient air pressure is not off-set by the air and nitrogen, a further movement of the H.C.U will cause the vent valve to open and admit atmospheric pressure to tank. This position of the H.C.U, would however only be reached if the P/D had reached a value of − 0.1 lbs ie a state of vacuum existed within the tank

EMERGENCY Provision is made within the vent valve for inward and outward emergency venting in the event of failure of the H.C.V.

The construction is as follows

(a) A diaphragm chamber in which the diaphragm is subjected to tank differential pressures.

(b) A push rod and ball valve.

(c) A spring loaded cone valve.

Both ball and cone valve are controlled by the diaphragm, and opening of either permits servo pressure (12 lbs□") to vent from vent valve bellows and so allow vent valve to open under pressure of its internal spring

OPERATION The diaphragm can move in either direction and tank pressure tends to move it downwards and static or ambient pressure tends to move it upwards

If the tank pressure for any reason exceeds 2.75 − 3.25 lbs□" the diaphragm will react downwards against the push-rod and ball-valve and force the spring loaded cone off its seating. Servo pressure will be vented from bellows of vent valve and tank will "vent" outwards

If tank pressure falls below − 0.125 the diaphragm will react upwards and relieve the spring pressure on the ball valve. The ball valve will allow servo pressure to escape, vent valve will open and tank will vent inwards.

VARIATIONS OF OPERATING CONDITIONS

	STATIC	START UP	GROUND	TAXYING.	CLIMB	ALT CRUISE	STRAIGHT DIVE	STEEP DIVE	EMERGENCY
VENT	OPEN	SHUT	SHUT	SHUT	OPEN	SHUT	SHUT	SHUT	OPEN
AIR	SHUT	OPEN	SHUT	SHUT	SHUT	SHUT	SHUT.	OPEN	OPEN
NITROGEN	SHUT.	OPEN	SHUT	OPEN	SHUT	OPEN	OPEN	OPEN	OPEN
P/D		+	2·4	2·4	3	2·4	2·4	2·2	-0·1

SERVICING.

GROUND TEST PANEL VULCAN

Located on inner rib of wheel bay and consists of four test points, two for compressor air charging and two for fuel tank pressure test. An ON/OFF cock is also provided to control the restricted P.2. for operations of air valve

Relief Valve In servo line to vent valve from M.C.U is a solenoid operated relief valve, the switch for which is mounted on the central console in the cock-pit

This relief valve allows all tanks to be vented immediately in event of a crash landing

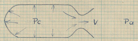
NOTE The central console control panel, situated between 1st and 2nd pilot, also carries nitrogen master cocks 2 off and also nitrogen pressure gauges 2 off

FUNCTIONAL TESTING.

ENGINE RUNNING.

1. Three switches in cockpit to be at NORMAL, These switches control nitrogen master cocks and air relief valve
2. Open restricted P^2 servo ON/OFF cock on panel
3. Attach gauges to each test connection on panel
4. Start engine and note that tank pressures rise and remain constant at between 2·75 and 3 lbs □". Should P/D be incorrect, investigate using fault finding chart in Vol 1.

No adjustments permissable any component assumed to be faulty must be exchanged



WHERE Pc = COMBUSTION CHAMBER PRESSURE.
Pa = AMBIENT PRESSURE.
V = EFFLUX VELOCITY.

ROCKETS.

ROCKET THEORY

In a rocket motor, chemical reaction produces gases at high temperatures and pressures. The rearward acceleration produced by high pressures and temperatures produces a forward reaction (see NEWTONS 2^{nd} & 3^{rd} LAWS). The ammount of "thrust" provided by this reaction depends on the change of momentum of the gases

Since Pc is greater than Pa, the gases will emerge with velocity V. which will be proportional to the pressure difference Pc – Pa As the P/D increases so will velocity increase until it reaches a maximum when Pa is at a minimum that is a vacuum.

Thus the thrust of a rocket increases with altitude.

Pc can be increased by a convergent outlet This will raise the P/D to sonic choke conditions, which when followed by a divergent nozzle will permit gases to expand to supersonic velocity. This type of nozzle is known as a CONVERGENT DIVERGENT, (DE LAVAL) and is usually termed a CON-DI NOZZLE.

ROCKET MOTOR CHARACTERISTICS.

1/ It differs from all other types of power units in as much as it carries its own supply of oxygen
2/ Its thrust is not adversely affected by surrounding conditions in fact it rises slightly with altitude
3/ Its power weight ratio is superior to any other power unit
4/ It has a very high propellant consumption

ROCKET MOTOR APPLICATIONS

a/ Assisted take-off units
b/ Mixed power formula

c. Auxiliary power units
d. Main power unit.

TYPES IN USE

a. Solid propellant
b. Liquid propellant.

SOLID PROPELLANT TYPE The simplest rockets are those that use a solid propellant i.e. fuel and oxidant contained in one mixture (MONO - PROPELLANT)

USES a. Short duration assisted take-off units (ATO)
b. Short range missiles
c. Pyrotechnics

LIMITATIONS a. Short Duration
b. Lack of control
c. Burning rate varies with temperature

LIQUID PROPELLANT TYPE These give increased duration and are divided into two general classes

a. Monopropellant where fuel and oxidant are together in one tank. Extremely careful selection is necessary to avoid danger of an explosion

b. Bi - PROPELLANT. Fuel and oxidant in separate tanks

CHOICE OF PROPELLANT A rocket propellant should have as many as possible of the following characteristics

a. High specific impulse
b. High density
c. Relatively easy to handle and store
d. Have as little influence on design as possible

CATALYST Any substance which increases the rate of a chemical reaction, but is itself unchanged at the end of the reaction.

ROCKET TERMS

SPECIFIC IMPULSE (S.I.) The thrust delivered per pound of propellant per second is lb/lb/sec

EXAMPLE 180 lbs of fuel will maintain 600 lbs of thrust for 60 secs. Thus 3 lbs of fuel are burnt each second therefore S.I. = $\frac{600}{3}$ = 200 lb/lb/sec.

DENSITY IMPULSE The specific impulse multiplied by the average specific gravity of the propellant mixture. It is a measure of the impulse per unit volume

TOTAL IMPULSE Is the product of the mean or average thrust multiplied by the duration in secs. expressed in lbs

PROPELLENTS USED

1 Solid Cordite is generally used in this country.

2 Liquids a FUELS Avtur or Avtag used in this country

b OXIDANTS

1 HYDROGEN PEROXIDE Known as High Test peroxide (H.T.P.) and this refers to concentrations of 80% - 90%. It is a clear non-inflamable liquid, with a slight ozone like smell. For the production of power, H.T.P is used by decomposing the liquid (H_2O_2) into superheated steam to form a high-pressure jet and also free oxygen. This high pressure jet can be used in two ways

1 To drive a turbine

2 As a propulsive jet (cold rocket).

To decompose the H.T.P. a catalyst is used such as —

a Silver
b Platinum
c Liquid Calcium Permanganate
d Lead
e Copper

H.T.P. CHARACTERISTICS.

SPECIFIC GRAVITY – 1.35

BOILING POINT – Approx 140°C, but liable to progressive rapid decomposition at temps above 60°C – Freezing point – 11°C

HANDLING RISKS Special fire risks due to ignition of organic materials such as wood rag etc when in contact with H.T.P. Contact with the skin will cause slight burning of a non-toxic nature. Antidote is liberal use of clean running water

Special protective clothing of a suitable plastic material must be worn.

STORAGE For long term storage pure aluminium tanks must be used to prevent run-down in peroxide strength. Tanks must be vented and the vents must incorporate filter traps to prevent ingress of foreign matter. Interior surface of tank must be perfectly smooth and clean. A water sprinkler system must be fitted above the tank and should be used if ambient temp exceeds 30°C. Phosphoric acid in suitable containers should be adjacent to storage tank for use as a stabilizer for the H.T.P in an emergency. If the acid is used however, the entire contents of storage tank must be returned to makers and must not be used in rocket motors. The makers do add a little sodium stannate to improve the storage qualities of H.T.P.

For short term use, ie tanks, pipelines and valves etc or rocket motors, stainless steel or certain aluminium alloys may be used

Gaskets and seals are of plastic such as polythene P.V.C or Polytetrafluraethylene (P.F.T.E.)

REMEMBER Wherever H.T.P. is used or handled running water must be available.

LIQUID OXYGEN

CHARACTERISTICS

A Blue Liquid, with chemical symbol $O_{\frac{1}{2}}$. It is relatively cheap £25 ton to produce and is available in unlimited quantities. Only a comparitively simple plant is needed to produce it

Boiling point — 183°C
Freezing point — 218°C

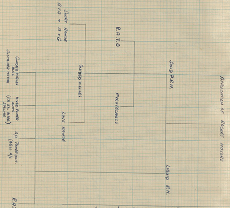
St Gravity at boiling point 1·14.

HANDLING Due to the intence coldness of LOX, asbestos gloves must be worn by the operator to protect the hands from the liquid and prevent them freezing to cold metal pipes and containers. Precautions against fire must also be taken.

STORAGE PRECAUTIONS

Due to high evaporation losses, LOX must be stored in special tanks The tanks consist of an inner and outer shell with either packing as an insulation between or a some ~~sort~~ types a of vacuum. Long term storage tanks are of copper or of copper alloy. For short term application pipes & valves etc on rocket motors the same materials are used.

Gaskets seals etc made from annealed copper or alluminium Materials must be carefully chosen, the low temperature of LOX causes many materials to become brittle and seals to deteriorate



R.J.T.V — RAM JET TEST VEHICLE (BRISTOL THOR NAPIER NRE-17). ENGLISH ELECTRIC

S.S.M (SURFACE TO SURFACE). MISSILE.

I.R.B.M INTERMEDIATE RANGE BALLISTIC MISSILE.

I.C.B.M INTER CONTINENTAL BALLISTIC MISSILE

A.A.M. AIR TO AIR MISSILE

S.A.M. SURFACE TO AIR MISSILE (BRITAIN — THUNDERBIRD) (USA — NIKE).

S.S.M SURFACE TO SURFACE MISSILE (USA BAZOOKA).

~~HANDLING~~

FILLING Rocket tanks should be filled just prior to take-off
a. To reduce evaporation losses
b. To prevent valves etc freezing up.

NITRIC ACID. (HNO_3)

CHARACTERISTICS Cheap and relatively easy to produce. [illegible] tin used widely in America but not in this country

SPECIFIC GRAVITY 1.52
BOILING POINT + 86°C
FREEZING POINT − 42°C

HANDLING This liquid will cause toxic burns, the vapour too is dangerous. In addition to normal protective clothing respirators must be worn.

IGNITION No ignition system is needed when nitric acid is used in a rocket motor. It has a positive hypergolic action when in contact with fuel.

Great care must be taken to see that N.A does not come into contact with petrol oil & grease etc.

STORAGE Very difficult to store due to its corrosive nature. For long term storage pure aluminium or certain zinc free alluminium alloy tanks. Short term i.e. pipes and valves etc on R.M' stainless steel and aluminium — Gaskets polythene or P.V.C.

SUPER SPRITE

An A.T.O unit for military and civil A/c

LEADING PARTICULARS

THRUST – 4,200 lbs (PEAK)

DURATION – 40 secs.

PROPELLANT { OXIDANT H.T.P 85%
KEROSINE (AVTUR)

MEAN SPECIFIC IMPULSE 150 secs

CATALYST SILVER

LENGTH $117\frac{1}{4}$ ins

DIAMETER $20\frac{1}{4}$ ins

WEIGHT EMPTY 620 lbs.

WEIGHT FUELLED 1460 lbs

PROPELLENT CONSUMPTION 20 lb/sec.

TOTAL IMPULSE 120,000 lb/sec.

SUPER SPRITE.

CONSTRUCTION.

H.T.P. TANK. Made of stainless steel and forms front part of the unit. Liquid capacity 54 gals with 3 gals air space Lifting eye fitted to forward end.

CHECK VALVE HOUSING. Fitted at rear end of H.T.P tank and houses a spring loaded H.T.P. check valve which opens at a pressure of 12 – 20 lbs □". It acts as a non return valve and ensures that no reversal of flow takes place between catalyst chamber and H.T.P tank.

CATALYST CHAMBER. Made of stainless steel with flanges at either end for attachment to H.T.P. tank and the combustion chamber. A grid at the rear end supports the catalyst pack. This pack consists of 90 circular gauzes silver deposited on nickel wire. They are located by a distance piece and a distributor plate.

FUEL INJECTION NOZZLE. Screwed into centre of catalyst chamber grid and fed by three radial passages formed in the webs of the grid.

FUEL CHECK VALVE. Controls flow of fuel to injection nozzle. Fitted on port side of catalyst chamber.

COMBUSTION CHAMBER Consists of an outer casing and a flame tube. Hot reaction takes place inside the flame tube and cold reaction on the outside. The outer casing is of stainless steel. The forward end supports the flame tube and the rear end forms the convergent divergent (con-di) nozzle. A flange is formed at rear of outer casing and to this is attached the forward flange of the fuel tank. An inner shroud fitted within the fuel tank enables fuel to be circulated around the throat of the con-di nozzle for cooling purposes.

KEROSINE TANK. Surrounds rear end of combustion chamber. Is of stainless steel and has a capacity of 5 galls. It carries the rear lifting eye.

NITROGEN BOTTLES. Nine in number, arranged radially around the unit. Are charged to 3,000 lbs ⊡" and the pressure is reduced for H.T.P and fuel tank pressurising to 550 lbs ⊡" by a reducing valve.

REDUCING VALVE, SAFETY VALVE & ACTUATOR

Mounted on port side of unit, between nitrogen manifold and fuel tank

DISTRIBUTOR BLOCK Mounted on stbd side of motor between nitrogen bottles and fuel tank

Consists of :– (1) Solenoid Valve
(2) H.T.P. Servo Valve
(3) Kerosine Servo Valve

MOTOR MOUNTINGS. Trunnions on either side of forward end of H.T.P tank. Further support provided by trunnions and swinging links on either side of fuel tank. Thrust pad at front of H.T.P. tank.

OPERATION The unit is operated electrically, two switches being employed. ie. 1 Safety Switch 2 Firing Switch

ACTION 1 Safety switch closed, firing switch operated.

2 The actuator motor operates the lever on safety valve and safety valve opens. Solenoid in distributor block is energised and solenoid valve is opened

3 Nitrogen at 550 lbs □" flows to bottom of H.T.P servo valve and so opens it. Nitrogen will now flow to pressurise H.T.P tank. H.T.P. will be forced out via the H.T.P check valve into catalyst chamber. Here it is decomposed into superheated steam and passes on into combustion chamber

4 Nitrogen also, after the H.T.P servo valve opens passes to underside of kerosine servo valve so opening this valve Nitrogen will now flow to pressurise the fuel tank

and fuel will be forced out of tanks via Kerosine check valve and injection nozzle into combustion chamber

5/ In the combustion chamber the kerosine burns with the free oxygen of the decomposed H.T.P (Exothermic combustion).

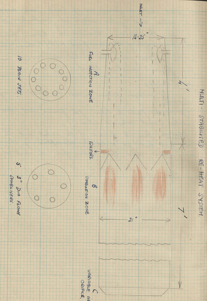
6 The resultant gasses are ejected via "con-di" nozzle to give forward reactive thrust.

SAFETY FACTORS

1/ If nitrogen pressure exceeds 800 lbs □" the safety valve will close

2 If this fails to happen, gas pressure will close solenoid valve against solenoid action

VENTING. Prior to operation of the rocket unit, the H.T.P and fuel tanks are vented to atmosphere by their respective servo valves. When these valves open, the vents are closed.



RE - HEAT

PURPOSE To decrease the take-off run of a jet aircraft and to increase it's combat efficiency

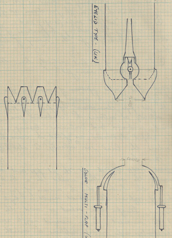
PRINCIPLES ① RE-HEAT or afterburning is based on the principle of burning additional fuel in the gas stream aft of the turbine

② The high air/fuel ratio (60-70/1) used in a gas turbine and necessary for reducing temperatures of gases, leave excess air available for the burning of additional fuel

③ The action of re-heat virtually turns the jet-pipe into a form of ram-jet.

DESCRIPTION Fuel injected updream of combustion zone in a region of high velocity, to ensure good atomization. A divergence in the jet-pipe downstream of fuel injectors reduces the gas velocity at entrance to combustion zone. To ensure efficient combustion and continuous burning, a number of cone-shaped stabilisers are fitted to cause eddying and so reduce the local gas velocity. A stabilized flame can thus form.

VARIABLE AREA ORIFICE If the jet pipe exit nozzle area remained the same there would be a back pressure felt on the turbine, due to increase of gas volume and choking of orifice. This would result in high turbine temperature. Therefore when reheat is used, the nozzle area must be increased. As an increased nozzle area would be a disadvantage under normal conditions a variable area orifice is essential.



TYPES OF ORIFICES USED.

1. EYLID TYPE (SWIFT)
2. SOLAR MULTI - FLAP (SABRE USA)
3. OCTAGONAL - FLAP (CRUSADER USA)
4. DOUBLE DOOR (FRANCE)

THRUST INCREASE The main factor in connection with re-heat is the temp ratio. This is ratio of the top re-heat temp to the turbine outlet temp.

The rise in temp will depend on the amount of fuel added, and to a certain extent the amount of oxygen in the gas stream.

Example Assuming top reheat temp = 1542°K and the turbine outlet temp = 913°K, then the temp ratio will be $\frac{1542}{913} = 1.69$

As the jet velocity will be increased as the square root of the temp ratio, the velocity ratio = $\sqrt{1.69} = 1.3$ to 1.

The the gas velocity is increased by 30% and the thrust also increases by 30%.

FUEL CONSUMPTION

When reheat is used, the S.F.C, will be approx doubled. This to a large extent is off-set by the fact that the time to climb to operational height is halved. If the use of reheat is limited to short time periods, it is a most effective method of thrust augmentation

MODERN DESIGN TRENDS Use of stabilisers in the form of guttering single or double is the common practice as is the use of the corrugated "HOWL SHIELD" giving noise control and circulation in the vicinity of the burners. Burner design is a simple as possible and the use of high energy ignition ensures efficient

FUEL CONSUMPTION AVON

CONDITION	← NON	HEAT ENGINE →		← RE-	HEAT ENGINE	→
	THRUST	G.P.H.	S.F.C	THRUST.	G.P.H.	S.F.C
STATIC	7,500	860	·920	9,450	22,50	1·900
700 M.P.H. S.L.	7,200	11,60	1·29	11,000	3120	2·280
700 MPH. 35,000'	3,000	4,50	1·20	4,600	1330	2·05
700MPH. 50,000'	1550	2,44	1·255	2,300	628	2·19.

light up under any operational conditions, ie at extreme altitude

FUEL INJECTION. Fuel system in general is similar to that of the engine system. The position of the burners will depend upon the design of the reheat chamber

IGNITION SPARK ignition must be provided, ensuring positive light up at extreme heights

ADVANTAGES OF RE-HEAT.

1. Uses same fuel as aircraft, This avoids complications of installation, servicing and also storage
2. Turbo-jet fuels are relatively safe whereas rocket propellants are usually very sensitive.
3. Additional weight is not excessive
4. An increase of 40% 50% thrust can be obtained without increasing frontal area.