DOCUMENT
GSM-G-CPL.003

DOCUMENT TITLE
AERODYNAMICS 2

CHAPTER 1 – RANGE AND ENDURANCE

Version 1.2
October 2013

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RANGE AND ENDURANCE

INTRODUCTION

During his epic crossing of the Atlantic Ocean, Charles Lindbergh had to overcome several problems. The limited fuel load that the aircraft carried was of major concern.

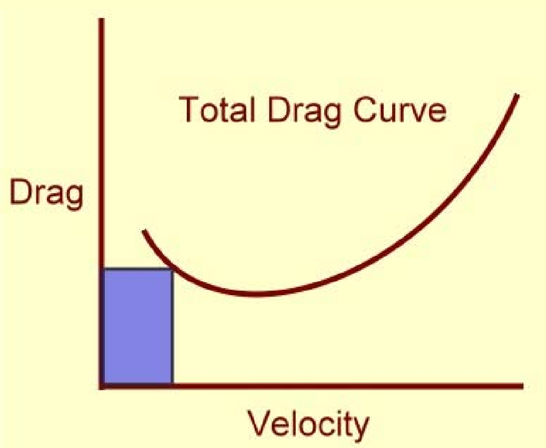
Consider Lindbergh's situation: Fly for maximum range (distance) is a technique that would have been followed for such a flight. Another technique is to fly for maximum endurance (time) that could be followed for a different type of flight.

The difference between the two techniques is best described by means of an example:

An aircraft with performance similar to that of Lindbergh's will have the following data:

- Fuel Load: 1000 litres
- V_{IMD}: 80 KIAS (120 KTAS at 10 000 ft) - Fuel Consumption: 20 l/hr.
- V_{MP}: 60 KIAS (60 KTAS at sea level) - Fuel Consumption: 15 l/hr

Speed for minimum power (VMP):

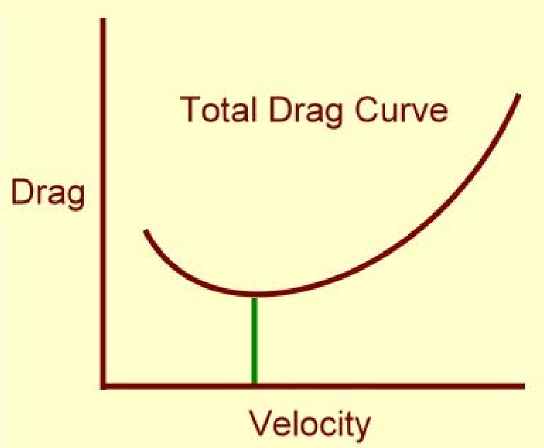


If the aircraft is flown at VMP the following results are obtained:

Endurance: **66 hrs, 40 min**
Range : 4000 nm

In this case the **endurance is a maximum**, but range is less than when flying at VIMD.

Speed for minimum drag (VIMD):



If the aircraft is flown at VIMD the following results are obtained:

Endurance: 50 hrs
Range : **6000 nm**

Although the endurance is less than when flying at VMP, the **range is a maximum**.

When flying for maximum range, the endurance of the aircraft will be somewhat less than maximum. The converse is also true. Here follows some applications for range and endurance flying:

Design criteria to obtain maximum range are one of the most important considerations in modern aviation. For commercial aircraft maximum economy is required. Combat aircraft with insufficient range is severely limited in operations.

Commercial Aircraft:

Economy is also an important consideration for military aircraft. For example, economy is a prime consideration for transport and utility aircraft, but less so for a fighter aircraft.

For a tanker aircraft holding for air-to-air refuelling the consideration is not range but rather that of endurance. The aircraft has to remain airborne for as long as possible to provide its services.

Tanker Aircraft:

Other military applications for endurance flight:

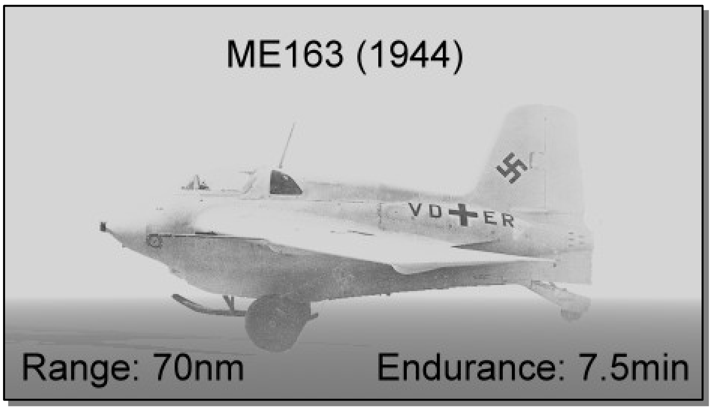
- **Maritime aircraft on area patrol.**
- **Elint aircraft.**
- **Command and control aircraft.**

The basic requirements for range flying are however quite different from that of endurance and then again the requirements differ for each of the main aircraft types: Piston, Jet and Turboprop.

BASIC REQUIREMENTS FOR RANGE AND ENDURANCE FLYING

The underlying principles of range and endurance flying are quite simple and they remain the same for all aircraft types:

- Range Flying. The aircraft is flown in such a way that the maximum load ***(mass)*** is delivered over a maximum distance, using minimum fuel.
- Endurance Flying. The basic requirement is that the aircraft is flown in such a way that it remains airborne for a maximum period of time using the minimum amount of fuel.



From the above it should be clear that the basic difference between range and endurance is that for range flying, energy is expended over distance and for endurance flying, energy is expended over time.

FLYING FOR RANGE: TURBOPROP AIRCRAFT

From the basic requirements of Range Flying it can be re-stated that range is the distance an aircraft could fly on a given amount of fuel. If all other factors ***(such as aircraft weight)*** are kept constant and if this distance is expressed as air distance, it is known as Specific Air Range (SAR).

MAXIMUM SPECIFIC AIR RANGE (SAR)

Specific Air Range is a useful parameter for the expression of aircraft performance and it is used as the departure point in determining the academic considerations with respect to Range Flying.

An equation for maximum SAR will now be derived....

The equation on the right is from the definition of SAR. The required format of this equation will be derived in six steps.

$$\text{SAR} = \frac{\text{Distance}}{\text{Fuel}} \quad \frac{\text{(Air nm)}}{\text{(Litre)}}$$

- **Step 1**

In the first step the equation is manipulated by multiplying with one and the components are then re-arranged.

$$\text{SAR} = \frac{\text{Distance}}{\text{Time}} \times \frac{\text{Time}}{\text{Fuel}}$$

- **Step 2**

Given:

$$\text{Speed (TAS)} = \frac{\text{Distance}}{\text{Time}}$$

A direct substitute can be made in the equation.

$$\text{SAR} = \text{TAS} \times \frac{\text{Time}}{\text{Fuel}}$$

Given:

$$\text{Gross Fuel Consumption (GFC)} = \frac{\text{Fuel}}{\text{Time}}$$

The inverse of the component must be substituted in the equation.

$$\text{SAR} = \text{TAS} \times \frac{1}{\text{GFC}} = \frac{\text{TAS}}{\text{GFC}}$$

- **Step 3**

GFC is only a general way of indicating operating efficiency. A more useful expression is obtained by relating fuel consumption to power produced. The measurement of fuel used per hour per Shaft Horsepower (SHP) is called Specific Fuel Consumption (SFC).

Given:

$$SFC = \frac{Fuel}{Time} \times \frac{1}{SHP}$$

GFC = Fuel/Time is substituted in the SFC equation.

$$\mathbf{SFC = GFC \times \frac{1}{SHP}}$$

The equation is rearranged....

$$\mathbf{GFC = SHP \times SFC}$$

and GFC is substituted in the SAR equation.

$$\mathbf{SAR = \frac{TAS}{SHP \times SFC}}$$

- **Step 4**

Rewrite the SAR equation in all its individual components:

$$\mathbf{SAR = \frac{TAS}{1} \times \frac{1}{SHP} \times \frac{1}{SFC}}$$

Efficiency of any system can be expressed as the ratio of power output over power input. For turboprop aircraft the Propeller Efficiency (PE) is expressed as the ratio of Thrust Horsepower (THP) over Shaft Horsepower (SHP). The following formula is used to complete the equation on the right:

Given:

$$PE = \frac{THP}{SHP}$$

Manipulate PE equation:

$$\mathbf{\frac{1}{THP} \times PE = \frac{THP}{SHP} \times \frac{1}{THP}}$$

Rearrange PE equation:

$$\mathbf{\frac{PE}{THP} = \frac{1}{SHP}}$$

Substitute in SAR equation:

$$\mathbf{SAR = \frac{TAS}{1} \times \frac{PE}{THP} \times \frac{1}{SFC}}$$

- **Step 5**

In level flight Thrust equals Drag and thus:

THP = Thrust x TAS or THP = Drag x TAS

A simple substitution for THP is done in the SAR equation:

$$SAR = \frac{TAS}{1} \times \frac{PE}{Drag \times TAS} \times \frac{1}{SFC}$$

TAS is factorised out:

$$SAR = \frac{\cancel{TAS}}{1} \times \frac{PE}{Drag \times \cancel{TAS}} \times \frac{1}{SFC}$$

$$SAR = \frac{1}{1} \times \frac{PE}{Drag} \times \frac{1}{SFC}$$

- **Step 6**

The equation is finally rearranged to obtain the desired format:

$$SAR = \frac{1}{Drag} \times \frac{1}{SFC} \times PE$$

The equation for SAR is presented in such a way that each component thereof represents a specific consideration:

$\boxed{\frac{1}{Drag}}$ = Airframe Consideration.

$\boxed{\frac{1}{SFC}}$ = Engine Consideration

$\boxed{PE}$ = Propeller Efficiency.

SAR, and hence range, will be a maximum if the product of the three components in the equation is a maximum.

Product of Components:

If the maximum SAR, and therefore maximum range of the aircraft is determined by the result of multiplying the components with each other, then clearly the greatest SAR will be obtained if each of the components is also a maximum.

Each of these components will now be considered separately....

AIRFRAME CONSIDERATIONS

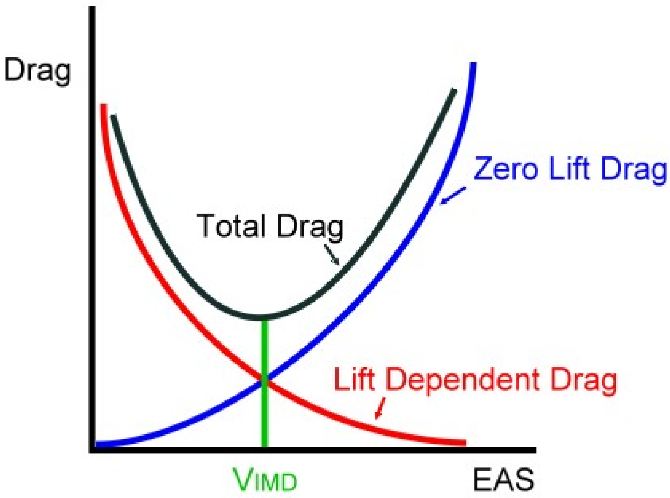
If the airframe is to be flown to its maximum efficiency it can be seen from the SAR equation that $\frac{1}{Drag}$. must be a maximum. In that case Drag must be a minimum.

Consider the hypothetical case where drag has a minimum and maximum value of 3500 lbs and 8000 lbs respectively.

In this case $\frac{1}{3500} = 0.000285$

and $\frac{1}{8000} = 0.000125$

From which it can be seen that $\frac{1}{Drag}$ is a maximum when Drag is a minimum.



Refer to the lesson on drag. The speed for minimum drag is found on the lowest point on the curve

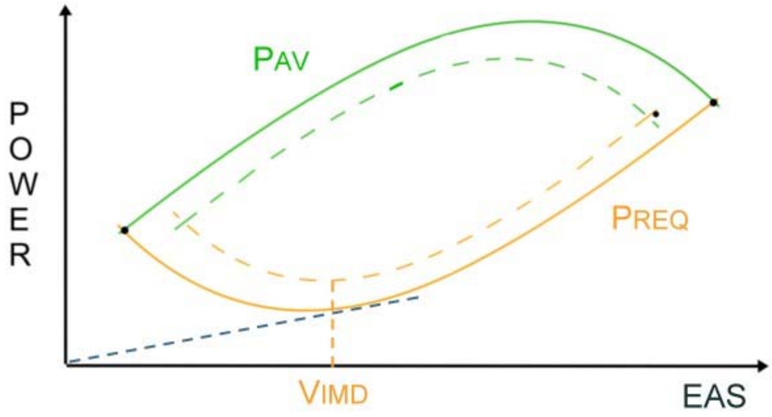
Remember that the speed for minimum drag is known as V_{MD} (or V_{IMD} when specifically referring to indicated airspeed).

From the foregoing it would be a simple matter to conclude that, with respect to range flying, the optimum airframe efficiency is obtained when Range Speed is equal to V_{IMD}. However there are some factors that must be considered:

- **Effect of Altitude**
- **Effect of Weight**
- **Effect of Wind**
- **Practical Considerations (RRS)**

EFFECT OF ALTITUDE

Although the PREQ increases with altitude, VIMD as well as the value of drag remains a constant at all altitudes.



Effect of Altitude on PREQ and PAV

Furthermore, VIMD is at the lower scale of the speed band of an aircraft, with the result that compressibility is unlikely to affect airframe efficiency at high altitudes.

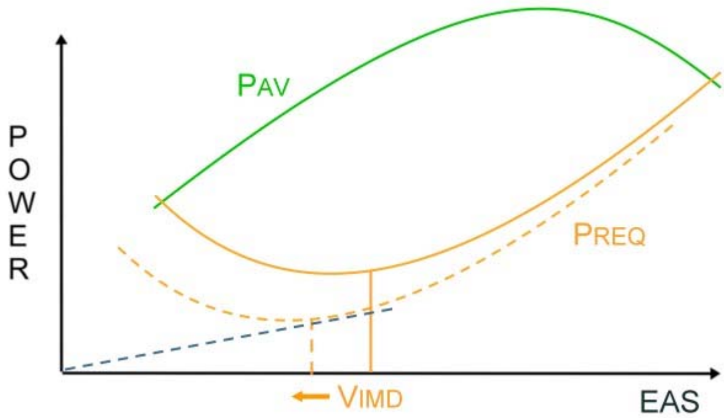
> **Compressibility:**
>
> **Refer to the IAS/EAS relationship covered in Aerodynamics I:**
>
> **When an object travels at 200 KIAS at sea level, air can be considered to be incompressible and under these conditions IAS = EAS.**
>
> **However, when flying 200 KIAS at 55 000 ft above sea level, the effects of compressibility cannot be ignored. The aircraft is actually flying at the speed of sound and there is approximately 20 kts difference between IAS and EAS.**
>
> **The overall effect of compressibility is that drag is increased, thus reducing airframe efficiency.**

EFFECT OF WEIGHT

Refer to the lesson on Straight and Level flight. A reduction in weight will reduce the power required to maintain level flight.

With a reduction in weight as fuel is burned, the required lift is reduced accordingly, resulting in a progressive reduction of induced drag:

Since **Power = Drag x TAS** it should be clear that there is a corresponding reduction in Power Required.



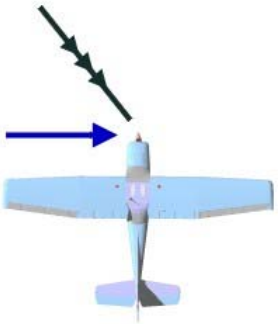
Effect of Weight Reduction on PREQ

Also note from the figure that the reduction of induced drag causes a reduction in VIMD.

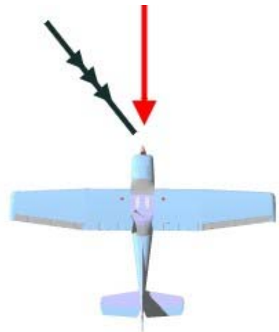
EFFECT OF WIND

Up to this point range has been expressed in terms of air nautical miles. However, since flights normally take place between geographical points, it is required to express range in terms of ground distance covered.

In the unlikely event of zero wind conditions, TAS is equal to groundspeed and air distance is equal to ground distance. Under normal conditions wind will be encountered during flight. Any wind that is experienced can be factorised into two components:



Crosswind. A wind vector perpendicular to the flight path of the aircraft, causing drift to the left or right of track.



Headwind or Tail Wind. A wind vector parallel to the flight path of the aircraft, causing the effective groundspeed of the aircraft to be increased in the case of a tail wind or decreased in the case of a headwind.

Since a tail wind assists by increasing groundspeed, it can be used to advantage in order to obtain maximum range. The question can be asked: Should the speed of the aircraft be reduced in order to prolong the benefit obtained by the tail wind?

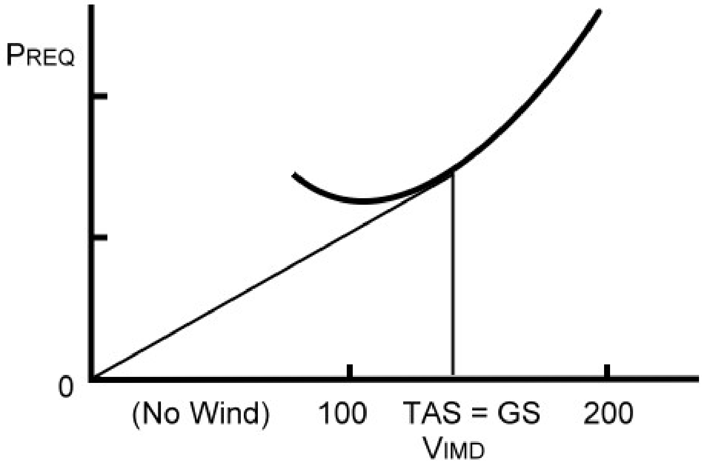
Conversely, a headwind opposes the progress of the aircraft over the ground and groundspeed is reduced. Clearly the range of the aircraft is reduced and in the event of a strong headwind could result in an aircraft being incapable of completing a particular route. Should the speed of the aircraft be increased in order to reduce the negative effect of the headwind?

The answer to the previous two questions lies in the study of the power required curves....

Under conditions of zero wind True Air Speed (TAS) is equal Ground Speed (GS). ***(TAS = GS)***

TAS vs GS in zero wind

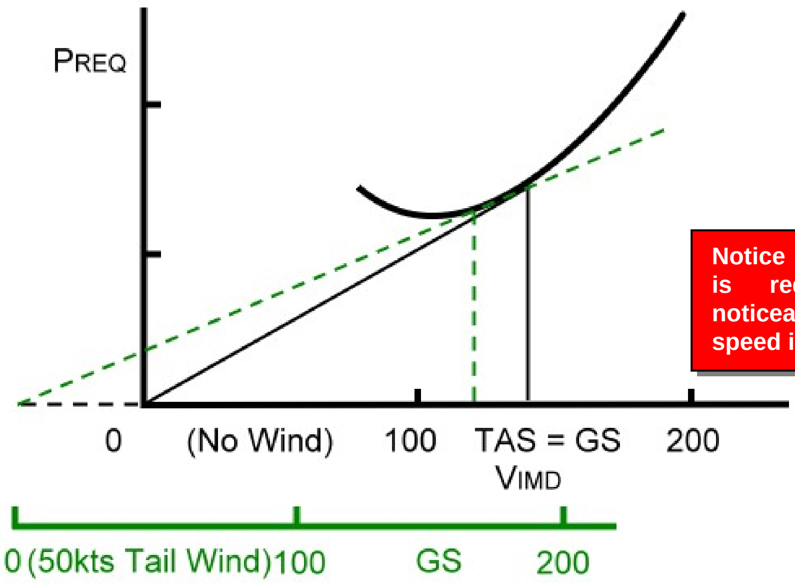
The aircraft is travelling through the air at a certain TAS. Since the air mass is stationary with respect to the ground under zero wind conditions, the speed of the aircraft over the ground is equal to TAS regardless of indicated airspeed or altitude.



Refer to the graph on the left: It demonstrates that optimum range speed is found at the tangent ***(from the origin)*** to the power-required curve.

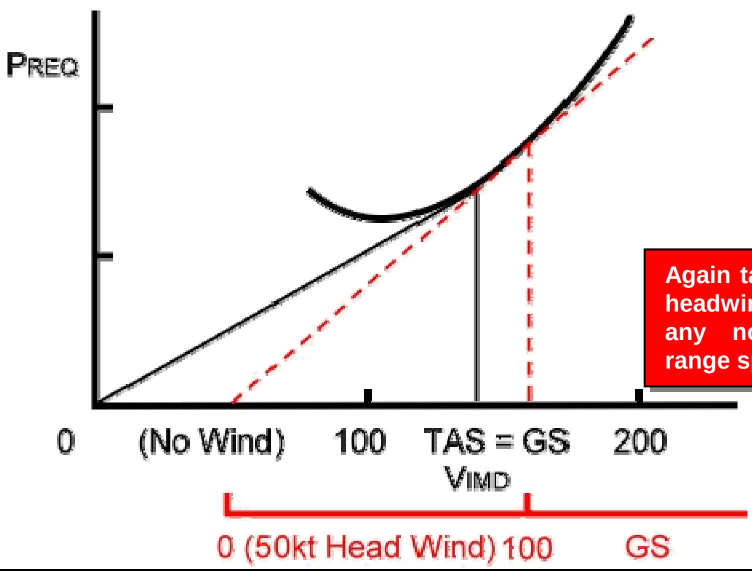
Under zero wind conditions this speed is VIMD.

With a tail wind, Ground Speed is increased, thus the origin of the graph is extended to the left, and a new tangent is drawn to the power-required curve to determine the optimum Range Speed for these conditions.

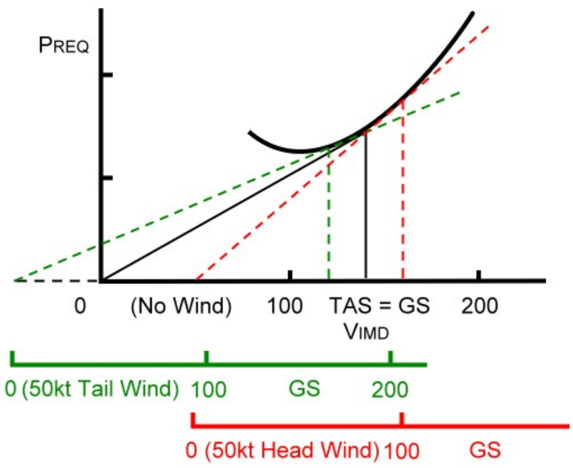


Notice that a strong tail wind is required before any noticeable change in range speed is noticed.

In event of a headwind, the origin of the graph is extended to the right, and a new tangent is drawn to the power-required curve in order to determine the optimum range speed.



Again take note of the strong headwinds required before any noticeable change in range speed is noticed.



In the example provided a 50 kt wind, which is 38% of the TAS at V_{IMD}, has the following effect on RRS:

Tail Wind: Recommended Range Speed (RRS) decreased by (8%)

Headwind: Recommended Range Speed (RRS) increased by (13%)

As can be seen from the foregoing, the effect of head and tail winds are relatively small on RRS. The following rule of thumb should be applied in practice:

Tail Winds. Reduce indicated airspeed by 10% of wind speed if tail winds stronger than 33% of TAS are experienced.

Headwinds. Increase indicated airspeed by 10% of wind speed if headwinds stronger than 25% of TAS are experienced.

Example 1:

Indicated Airspeed: 160 KIAS
TAS: 230 kts
headwind component: 60 kts

Wind component: 26% of TAS
Rule of Thumb: 10% of wind
= 6 kts
New airspeed: = 166 KIAS

Example 2:

Indicated Airspeed: 134 KIAS
TAS: 175 kts
headwind component: 40 kts

Wind component: 22.8% of TAS
Rule of Thumb: No adjustment
New airspeed: = 134 KIAS

Example 3:

Indicated Airspeed: 160 KIAS
TAS: 230 kts
tail wind component: 78 kts

Wind component: 34% of TAS
Rule of Thumb: 10% of wind
= 7.8 kts
New airspeed: = 152 KIAS

Example 4:

Indicated Airspeed: 160 KIAS
TAS: 230 kts
tail wind component: 60 kts

Wind component: 26% of TAS
Rule of Thumb: No adjustment
New airspeed: = 160 KIAS

PRACTICAL CONSIDERATIONS (RRS)

You have now seen that, with respect to airframe considerations, the aircraft should be flown at V_{IMD}. However, in practice aircraft are flown for range at a speed slightly faster than V_{IMD} for the following two reasons:

When flying at V_{IMD} any turbulence or manoeuvres will cause a loss of lift and height. This height can only be regained by the application of more power and consequent wastage of fuel. A higher speed therefore ensures a margin for such events.

The tangent to the power curve represents the optimum range speed for any given condition. However any small increase in speed from V_{IMD} will result in a faster flight without undue loss of range.

Turboprop aircraft are thus flown at a Recommended Range Speed (RRS), which is some 10% to 20% higher than V_{IMD} and is specified in the Aircraft Flight Manual (AFM) for that aircraft type.

Summary of Airframe Considerations:

Ideally, the aircraft should be flown at the Recommended Range Speed (RRS), which is slightly higher than VIMD, at any altitude, with a power setting to maintain RRS.

Speed is only varied when conditions of very strong head or tail winds are experienced.

ENGINE CONSIDERATIONS

From the SAR equation it was seen that 1/SFC is required to be a maximum. In order to achieve this SFC must in turn be a minimum.

SFC

Earlier in the lesson SFC was defined as fuel used per hour per Shaft Horse Power (SHP).

Several factors affect the SFC of a Turboprop engine, and thus also the range of the aircraft. The following factors will be considered:

- **RPM**
- **Altitude**
- **Forward Speed**

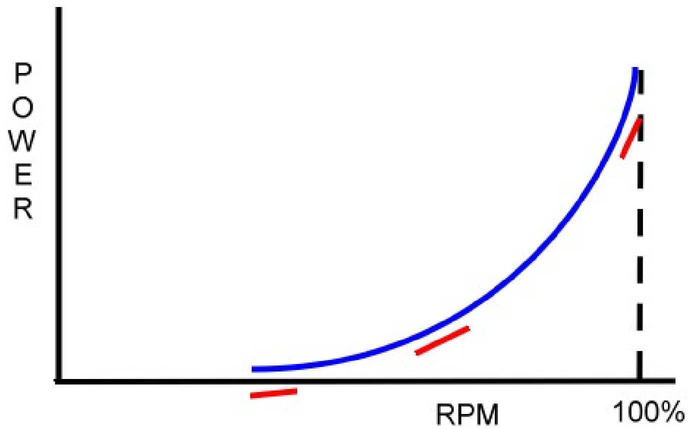
RPM

The performance of a Turbine engine is directly proportional to the engine RPM. The topic is fully covered in the lesson on engines and only the relevant facts will be repeated here:

At minimum engine rpm the turbine absorbs all available power in order to sustain the operation of the engine.

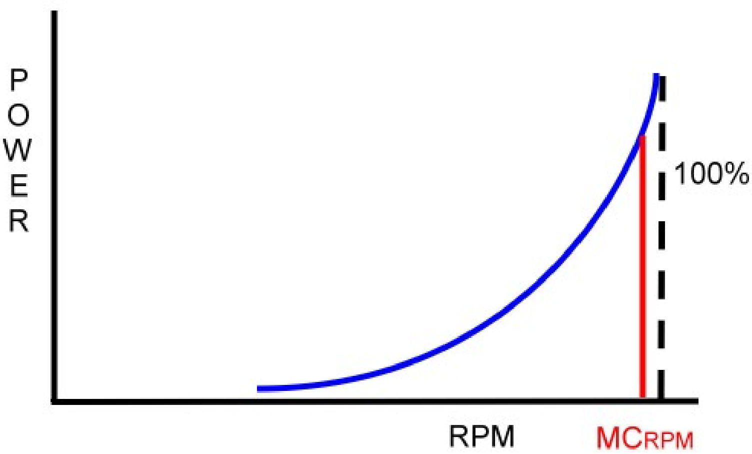
With increased fuel flow, engine rpm increases and the engine generates some power. However it is only under conditions of high fuel flow, and high engine rpm, that power output becomes significant.

Since efficiency is measured as a ratio of energy input versus energy output, the efficiency of turbine engines is only high when operating between 90% to 100% rpm.



Effect of Engine RPM on Power Output

By design turboprop engines operate most efficiently at only one RPM setting, known as Maximum Continuous RPM (MCRPM).



Most Efficient Operation: Turboprop Engines

In order to obtain minimum SFC the engine must be operated at MCRPM at all times.

ALTITUDE

Refer back to the Meteorology lesson on the Atmosphere. Temperature decreases with an increase in altitude.

Temperature Change with Altitude

According to ISA the sea level temperature is 15.0ºC. The temperature lapse rate is 1.98ºC per 1000 ft, up to 36090 ft, where after temperature remains constant at -56.5ºC.

In cold air the thermal efficiency of a turbine engine is improved. Hence the SFC is also improved with an increase in altitude.

Thermal Efficiency

A turbine engine operates more efficiently in cold air due to the fact that air mass flow through the engine is increased.

Now refer back to the meteorology lesson on density.

Air density decreases with an increase in altitude.

Density Change with Altitude

From the Meteorology lesson on Density it was seen that density decreases with altitude for the following reasons:

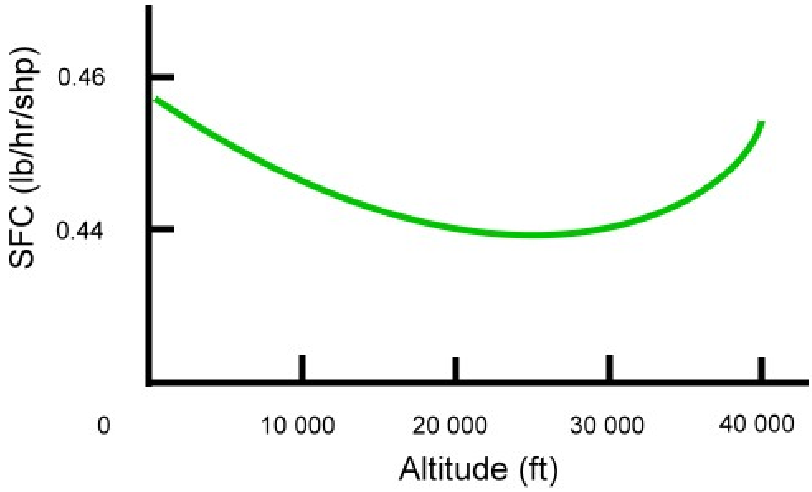
- **Reduction in pressure with altitude would result in a reduction of density.**
- **Reduction in temperature with altitude would result in an increase of density.**
- **The reduction in pressure has the overriding effect.**

The reduction in density results in a reduction in engine power ***(which would result in a deterioration of SFC if not compensated for)***. However the Barometric Fuel Control Unit (BFCU) of the engine maintains a constant fuel/air ratio and the SFC is thereby kept a constant.

From the foregoing it was seen that SFC will improve ***(becomes less)*** with a decrease in temperature and that it remains constant with the reduction in density.

The combined effect is that SFC will actually improve as altitude is increased. However, at high altitudes efficiency of the propeller begins to fall ***(due to the decrease in density)*** and causes SFC to increase.

The overall effect of altitude is illustrated on the SFC vs Altitude graph on the right.



FORWARD SPEED

With an increase in forward speed the air mass flow through the engine will improve, resulting in increased engine power.

Ram Energy. ***(Refer to the IAS/EAS relationship.)***

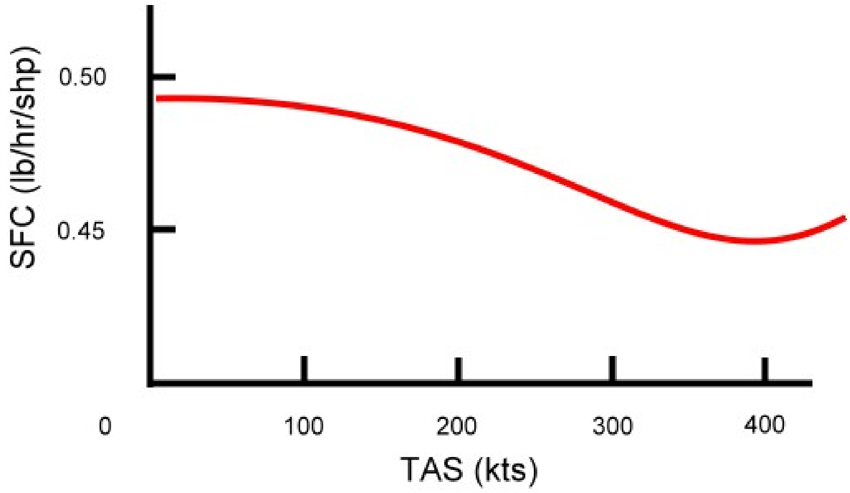
Air is compressible, and at high forward speeds the compression of air causes an increase in energy in the engine compressor, leading to an increase in engine efficiency.

This topic is covered fully in the lesson on Engines.

The BFCU maintains a constant fuel/air ratio and fuel consumption is increased, but because of the gain in ram energy the SFC is constantly improving with an increase in speed.

At a sufficiently high speed a rapid deterioration of SFC will be experienced due to the effect of propeller efficiency.

The overall effect of aircraft speed is illustrated on the SFC vs Airspeed graph on the right.



Summary of engine considerations.

Maximum engine efficiency (low SFC) is obtained under the following conditions:

- **Operating at MCRPM (engine design).**
- **Operating at high altitude (better thermal efficiency).**
- **Operating at a high TAS of 300 to 400 kts (advantage taken of ram effect while propeller efficiency is still high).**

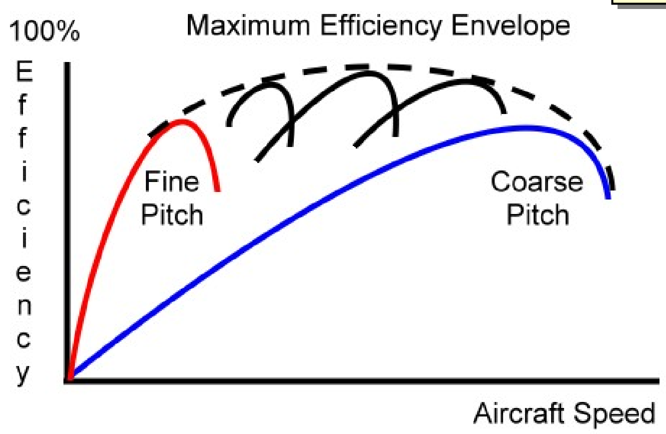
PROPELLER EFFICIENCY

Refer back to the lessons on Propeller Theory. Efficiency over wide speed range can be considered the main advantage of a constant speed propeller when compared to a fixed pitch propeller.

Advantages of constant speed propeller:

A constant speed propeller assembly is actually heavier and more complex than the fixed pitch design.

Depending on the pitch of the fixed pitch propeller it could actually facilitate a higher forward speed than the constant speed propeller. However, the fixed pitch propeller has optimum efficiency at only one specific forward speed.

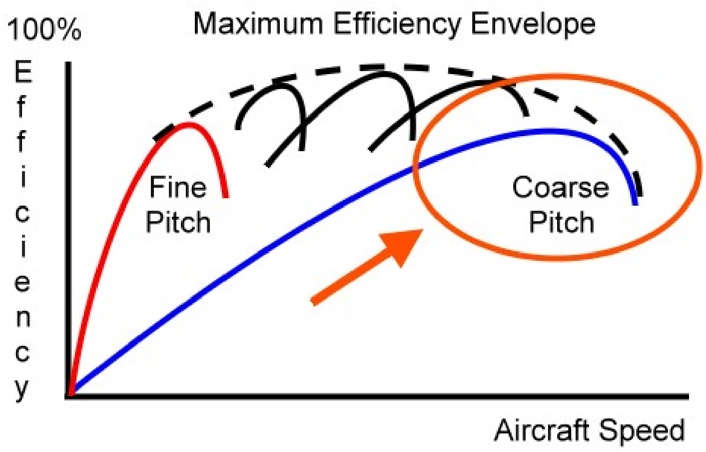


With the efficient design of modern turboprop aircraft, propeller efficiency is maintained over a wide forward speed range. However, efficiency is affected at high forward speed and high altitude.

FORWARD SPEED

As can be seen from the graph, propeller efficiency decreases rapidly at high forward speed.

This reduction in propeller efficiency has a direct negative effect on SAR as well as an indirect effect, as SFC increases in order to obtain greater forward speeds.



ALTITUDE

With an increase in altitude air becomes less dense. This reduction in density affects the propeller efficiency.

At low and medium altitudes the reduction in propeller efficiency is negligible, but at high altitudes ***(above 30 000 ft)*** it results in a negative effect on SAR.

As altitude is further increased SFC will also increase due to the reduction in propeller efficiency, thereby reducing SAR even further.

Propeller efficiency remains optimum:

- **For the greater part of the aircraft speed range and only decreases at the higher end thereof.**
- **For low and medium altitudes.**

COMBINED CONSIDERATIONS

It was said that SAR would be a maximum if the product of the three components were a maximum. The absolute maximum SAR would of course occur if each of the components of the equation were also a maximum.

However, from the foregoing work you should be aware of the conflicting requirements of the individual components. Conflicting airframe and engine considerations in particular, poses problems in this regard.

A practical compromise must be reached where maximum range is obtained within the set of constraints as determined by the individual components of the SAR equation.

The relevant constraints will be listed, where after the final criteria for range flying in a turboprop aircraft will be stated:

Range Flying Constraints, Turboprop Aircraft: Constraints with respect to speed, altitude and power settings are compared with the aid of colour:

- **Airframe Considerations**. The aircraft should be flown at a **low speed**, slightly higher than V_{IMD} (RRS), at **any altitude**, with a **low power** setting to maintain RRS. Speed is only varied when very strong head or tailwinds are experienced.

RRS: Recommended Range Speed:

That speed normally 10% to 20% higher than VIMD, where stability problems associated with VIMD is eliminated and where faster flight is obtained with minimal loss of range.

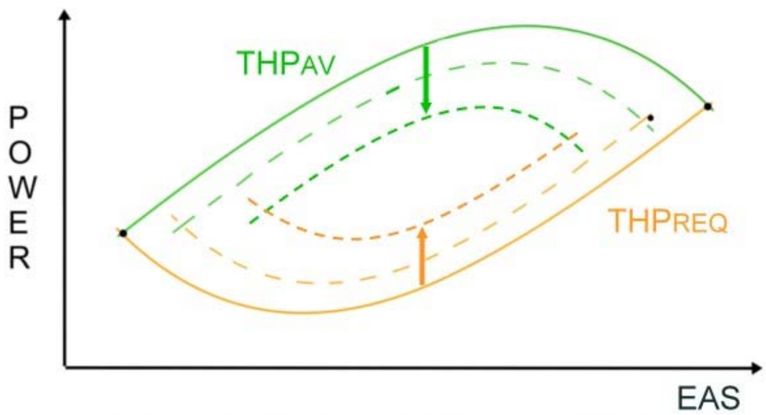
- **Engine Considerations**. The aircraft should be flown at **high power** setting (MC_{RPM}), **high TAS** and at **high altitude**.

Maximum Continuous RPM:

By design turboprop engines operate most efficiently at only one RPM setting. This RPM setting is known as Maximum Continuous RPM (MCRPM) and in order to obtain minimum SFC the engine must be operated at MCRPM at all times.

- **Propeller Efficiency**. Propeller efficiency deteriorates at high speed and high altitude, thus requiring **low or medium speed and low or medium altitude**.

Solution. The optimum SAR can be obtained by compromise. The solution lies in the effect of altitude on the power curves:



Effect of Altitude on THPREQ and THPAV

Refer once again to the Lesson on Straight and Level Performance. The Power Available (P_{AV}) decreases and Power Required (P_{REQ}) of a power producing aircraft increases with an increase in altitude.

Maximum Altitude

It is often the case with modern aircraft that the absolute ceiling of the aircraft is not determined by performance, but rather by other criteria, such as pressurisation systems, oxygen supply systems, etc. This design limitation must be adhered to at all times.

If altitude is increased sufficiently, a point will be reached where the power available at MC_{RPM} is equal to the power required to maintain RRS.
For maximum range the aircraft is to be flown at this

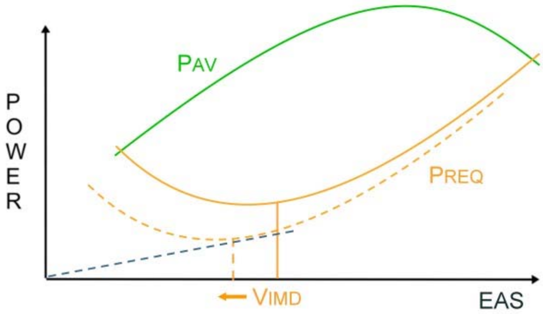
maximum altitude.

A Study of the power curves reveal that for range flying in a turboprop aircraft, the best solution is obtained when the aircraft is flown at RRS, at maximum altitude where the power required to maintain this speed is MC_{RPM}.

CRUISE CONTROL

From the previous section it was seen that for maximum range the aircraft is flown at that maximum altitude where the power required to maintain RRS is MC_{RPM}.

The influence of a reduction in weight on the power curves has been revised earlier in the lesson, and you will remind yourself that P_{REQ} was continuously reduced with weight as fuel was burned:



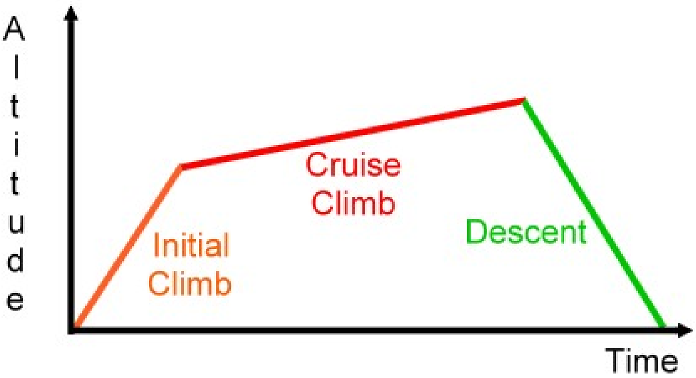
Effect of Weight Reduction on P_{REQ}

V_{IMD} and hence RRS is continuously reduced.

The maximum altitude at which the aircraft can fly is continuously increased as P_{REQ} reduces.

The result hereof is a Cruise Climb where further climb becomes possible due to the reduction in weight, while flying at a continuously reducing indicated airspeed.

For a flight involving a cruise climb, the initial altitude to start the cruise will depend on weight and air temperature and can be calculated from data obtained in the Aircraft Flight Manual (AFM).



Cruise Climb Profile

MC_{RPM} and RRS are maintained throughout the cruise. Ideally, the indicated airspeed of the aircraft should be reduced continuously, but in practice half hourly adjustments in speed is made while a slow climb is maintained.

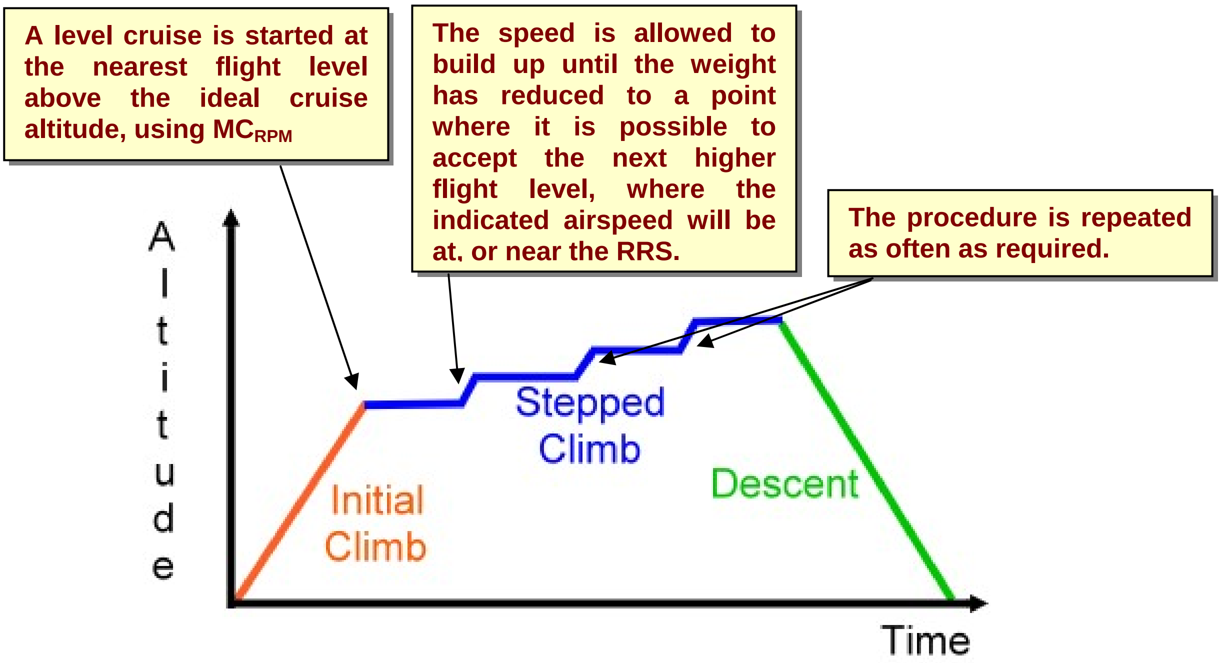
When cruise climbing is utilised, the absolute maximum range is obtained.

Cruise climbing places a high workload on the aircrew due to the amount of calculation involved.

ATC (Air Traffic Control) Procedures:

Aircraft are assigned specific Flight Levels according to the semi-circular rule, to facilitate an orderly flow of traffic, and prevent hazardous situations arising from conflicting traffic. ATC procedures are fully covered in the lessons on Airmanship.

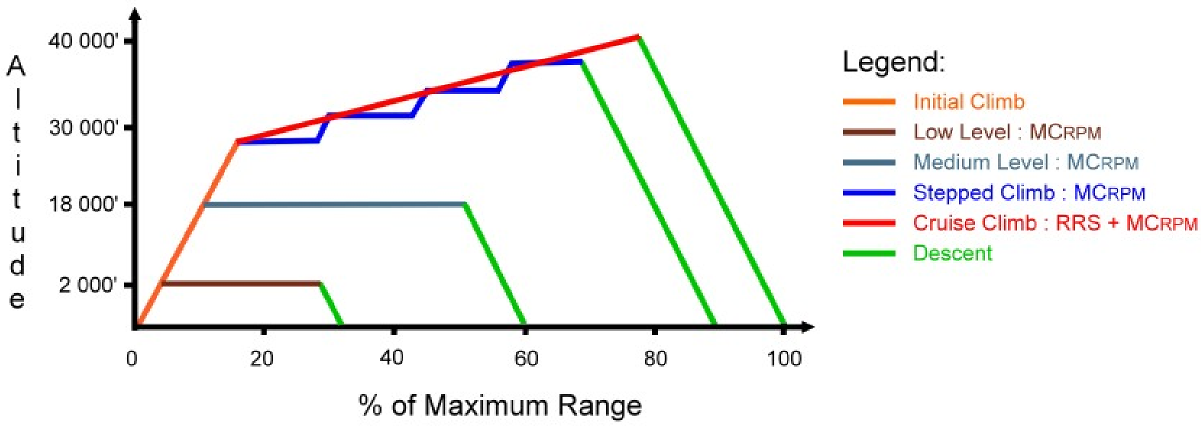
Unfortunately, due to ATC procedures, cruise climbing can often not be allowed. In these circumstances the best range can only be obtained by a stepped cruise:



Stepped Climb Profile

The main disadvantage of stepped cruising is a high workload on the aircrew due to the amount of calculation involved.

Various range profiles for a turboprop aircraft are illustrated on the graph below. The range is expressed as a percentage of the maximum obtainable range.



Range Profiles: Turboprop Aircraft

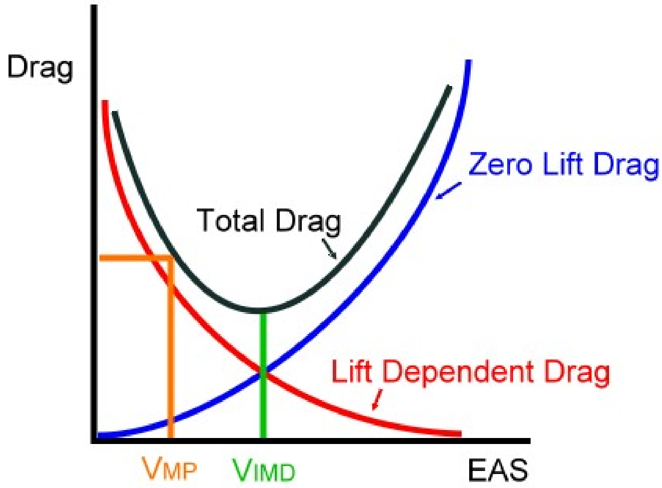
FLYING FOR ENDURANCE: TURBOPROP AIRCRAFT

Refer back to the beginning of this lesson, it was stated that the basic requirement for endurance flying is that an aircraft is flown in such a way that the aircraft remains airborne for the maximum period of time using the minimum amount of fuel.

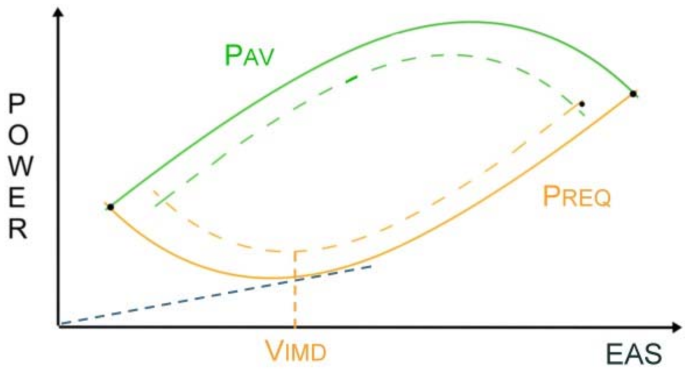
It can be assumed that the fuel consumption of an engine depends upon the amount of power produced by that engine. In the case of endurance flying it is the power produced for the aircraft to remain airborne for a maximum period of time. There are two factors that determine the minimum fuel flow: Minimum Power Required ***(Airframe consideration)*** and Minimum SFC ***(Engine consideration)***:

MINIMUM POWER REQUIRED (AIRFRAME CONSIDERATIONS)

Refer back to the lesson on Drag. The speed for minimum power obtained on the minimum area under the drag curve.



From the figure it can be seen that the value of drag at V_{MP} is actually higher than at V_{IMD}, yet the power required is a minimum. This is because ***Power = Drag x TAS*** and since the reduction in TAS is greater than the increase in drag, the resultant power required is less at V_{MP}.



Effect of Altitude on P_{REQ} and P_{AV}

You will also remember from earlier work revised in this lesson that power required is increased with an increase in altitude, as indicated on the power curve.

The result from the foregoing is that with respect to airframe consideration, the aircraft is to be flown at V_{MP} with a minimum power setting at the lowest possible altitude.

MINIMUM SFC (ENGINE CONSIDERATIONS)

The factors affecting SFC were covered during range flying and will simply be summarised here:

- With regard to engine design: The engine should be operated at maximum continuous power MC_{RPM}.

- Concerning thermal efficiency: The aircraft should be operated at high altitude.

- The aircraft should be operating at high TAS ***(of 300 to 400 kts)*** to take advantage taken of ram effect while propeller efficiency is still high.

COMBINED CONSIDERATIONS

Combined Effect. The resultant requirements with respect to endurance flying are thus the following:

The airframe requires flight at V_{MP} with the engine set at low power to maintain this speed.

Engine requirements are a high power setting and high forward speed at high altitude.

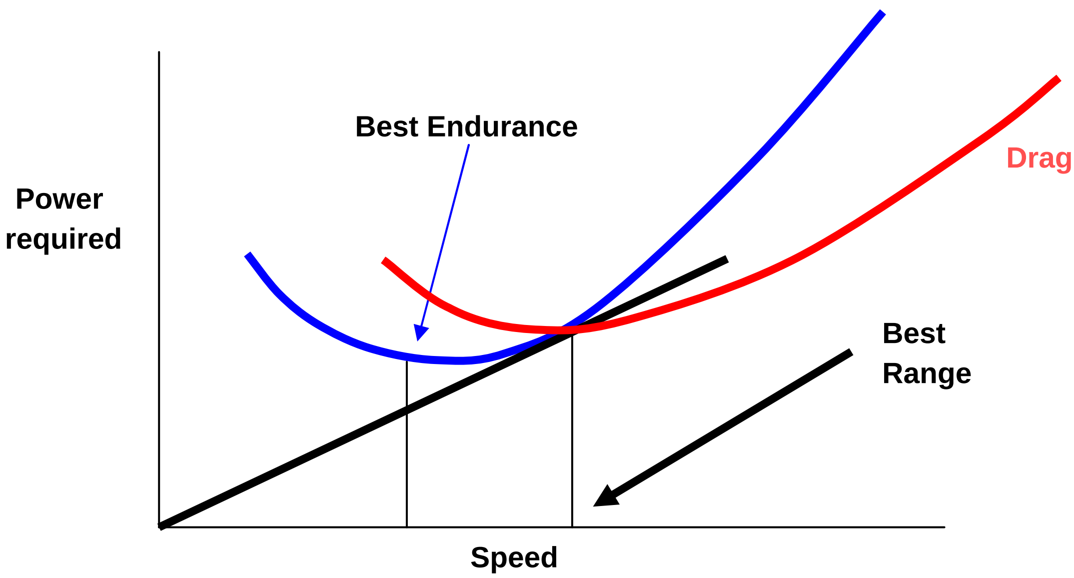
Obviously these requirements are conflicting and a compromise is achieved when the aircraft is flown at medium altitude in the region of V_{IMD} with the engine(s) throttled in order to maintain this speed.

For endurance flying, the best compromise is achieved when the aircraft is flown at medium altitude in the region of VIMD with the engine(s) throttled in order to maintain this speed.

PISTON AIRCRAFT

RANGE

To achieve Best range in a piston engine aircraft, we must first set the aircraft up for minimum drag. This is achieved at 4 degrees angle of attack. This is the bottom of the Drag Curve. Because it is a Piston engine we can use the Power Required curve to find our besr range speed by drawing tangent to the curve and where it cuts the Power Required curve is our Best Range Speed.



And then if we lay the Drag curve over the top we can see that this speed coincides with the bottom of the Drag Curve which is Minimum Drag.

So, we have the airframe sorted for best range, what do we do with the engine?
To achieve Best Range, we must reduce our fuel burn to maximise our range.
Best Performance for a normally aspirated (Non augmented or non super or turbo charged engines) is achieved at FullThrottle Height (FTH) which is sea level. Remembering that FTH is the altitude above which, the engine cannot maintain a selected manifold pressure (MAP).

This means the engine requirements are:
Lowest RPM and Highest MAP possible and lean mixture to produce the horsepower required to fly at that speed without causing the engine distress.
However the height to be flown may be determined by ATC or terrain, so a compromise may be necessary.

Augmented Engines

In the case of supercharged or turbocharged engines, the Full Throttle Height is much higher depending on the amount of boost above sea level pressure that the system can provide.
If sea level performance can be maintained at a higher altitude then our TAS will be higher, so the aircraft is flying a lot faster for a small increase in fuel burn , so the miles per gallon just got better and therefore our range.

CRUISE CONTROL

Piston engine aircraft are normally flown at a constant altitude (FTH), due to the design and operation of the supercharger. Maximum range is obtained by utilising one of the following techniques (listed in order of efficiency):

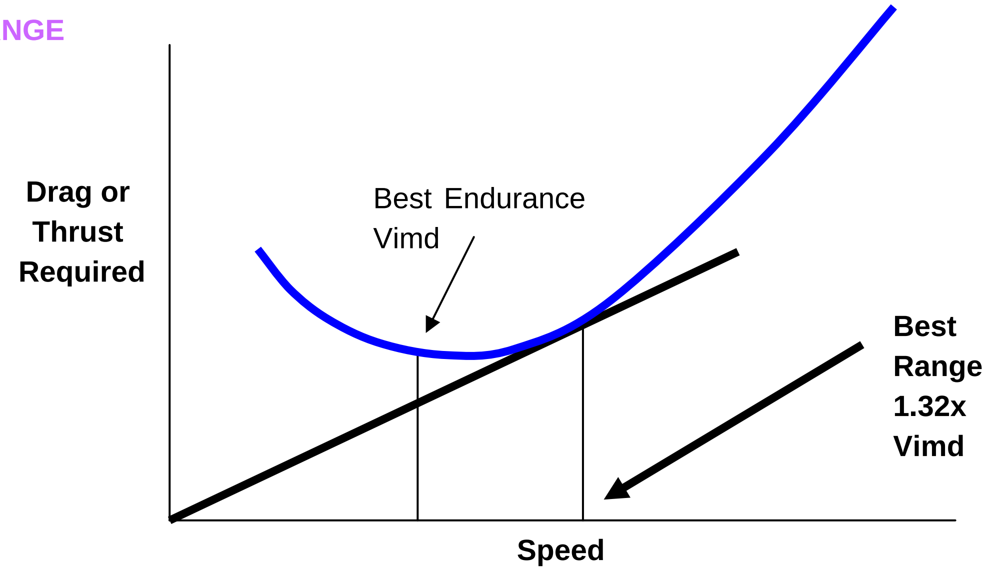
- Flying at a reducing RRS. ***(Maximum range, Complicated procedure. Flight planning difficult. Slowest flight.)***
- Flying at constant RRS. ***(Flight planning simplified.)***
- Flying at a constant power setting. ***(Most suitable for short distances. Flight planning difficult. Shortest flight time.)***

ENDURANCE

The aircraft is flown at the lowest, safe, practicable altitude at the speed for Minimum power, which would be just a bit faster than the stall speed. Engine requirements are the same as for range, lowest RPM, Highest MAP, with mixture lean.

JET AIRCRAFT

RANGE



Maximum range is achieved by flying the aircraft at a speed 32% higher than minimum drag speed (1.32 V_{IMD}) at high altitude where the engines operate at Optimum RPM. Should the effects of compressibility become a factor at extremely high altitudes, the aircraft is flown at a constant Mach No as specified in the Aircraft Flight Manual (AFM).

CRUISE CONTROL

The principles of cruise control are similar to those of turboprop aircraft, with maximum range obtained by flying a cruise climb profile. When a stepped climb profile is utilised, range is 95% of maximum. When a constant altitude is dictated, the following techniques may be utilised (listed in order of efficiency):

- Constant angle of attack. ***(Engine thrust must constantly be reduced. Flight planning is complex. Slowest flight.)***
- Constant IAS. ***(Engine thrust must constantly be reduced. Easiest flight planning.)***
- Constant thrust. ***(Flight planning is complex. Shortest flight time.)***

ENDURANCE

Maximum endurance is achieved by flying at an altitude where V_{IMD} is maintained with Optimum RPM set. If low altitude is dictated, engines can be shut down in order to use Optimum RPM on the remainder engine(s). Alternatively, near-optimum rpm is used to maintain V_{IMD}.