Flight Operations Support & Line Assistance

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getting to grips with fuel economy

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AIRBUS

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1. SUMMARY

Fuel Consumption is a major cost to any airline, and airlines need to focus their attention on this in order to maintain their profitability. This brochure looks at all the significant operating variables that affect fuel economy for the current Airbus range of aircraft.

This brochure shows that there are many factors that affect fuel consumption and that the potential gains and losses are huge. Most of these factors are directly controlled by the airlines own employees (flight crew, operations/dispatch, maintenance, etc.).

It can be also seen that what is good for one type of aircraft is not necessarily good for another, and that certain conceptions regarding best techniques for fuel economy are wrong.

Finally for a fuel and cost economic airline, the following are the main features:

- Good flight planning based on good data.
- Correct aircraft loading (fuel weight and CG).
- An aerodynamically clean aircraft.
- Optimal use of systems (APU, Bleed, Flaps/Slats, Gear, etc).
- Flight Procedures using speeds and altitudes appropriate to the companies economic priorities.
- Use of the FMGS in the managed mode.
- Use of performance factors in flight planning and in the FMGS derived from an ongoing aircraft performance monitoring program.

2. PREAMBLE

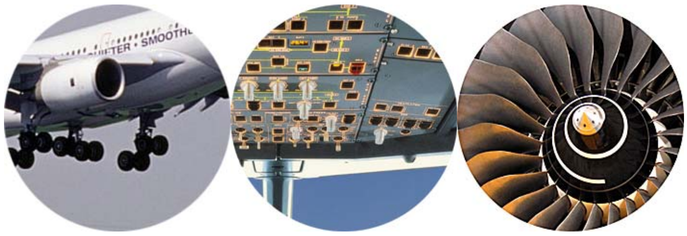
The very competitive and deregulated aviation market as well as the fear of a fuel price rise have made airlines understand how important it is to work on the fuel consumption of their fleet. Indeed airlines try to reduce their operational costs in every facet of their business, and fuel conservation has become one of the major preoccupations for all airlines, as well as aircraft manufacturers. That's why all ways and means to reduce fuel costs have to be envisaged, safety being of course the number one priority in any airline operation.

The purpose of this document is to examine the influence of flight operations on fuel conservation with a view towards providing recommendations to enhance fuel economy.

It is very rare that the reduction of fuel used is the sole priority of an airline. Such instances are to maximize range for a given payload, or to decrease fuel uplift from a high fuel cost airport. Generally fuel is considered one of the direct operating costs and an airline tries to minimize total direct operating costs. This introduces the concept of Cost Index and is the scope of another brochure (Getting to Grips with the Cost Index). However it is sometimes necessary to consider the cost implication of a fuel economy, and this is done where necessary in this brochure.

This brochure systematically reviews fuel conservation aspects relative to ground and flight performance. Whilst the former considers center of gravity position, excess weight, flight planning, auxiliary power unit (A.P.U.) operations and taxiing, the latter details climb, step climb, cruise, descent, holding and approach.

None of the information contained herein is intended to replace procedures or recommendations contained in the Flight Crew Operating Manuals (FCOM), but rather to highlight the areas where maintenance, operations and flight crews can contribute significantly to fuel savings.



3. INTRODUCTION

This brochure considers the two flight management modes: "**managed**" mode and "**selected**" mode.

The **managed mode** corresponds to flight management by means of a dedicated tool, the flight management system (FMS). Crews interface through the multipurpose control and display unit (MCDU) introducing basic flight variables such as weight, temperature, altitude, winds, and the cost index. From these data, the FMS computes the various flight control parameters such as the climb law, step climbs, economic Mach number, optimum altitude, descent law. Hence, when activated, this mode enables almost automatic flight management.

When in managed mode, aircraft performance data is extracted from the FMS database. This database is simplified to alleviate computation density and calculation operations in the FMS, but individual aircraft performance factors can produce good correlation with actual aircraft fuel burns.

When in **selected mode**, crews conduct the flight and flight parameters such as speed, altitude, and heading have to be manually introduced on the flight control unit (FCU).

The **cost index (CI)** used in the managed mode provides a flexible tool to control fuel burn and trip time to get the best overall economics. A technique that reduces fuel burn often requires more trip time. Hence fuel savings are offset by time related costs (hourly maintenance costs, flight and cabin crew costs and marginal depreciation or leasing costs). The cost index is the cost of time ($/min) compared with the cost of fuel ($/kg) and is used to obtain the best economics.

If fuel costs were the overriding priority, because fuel costs were much more significant than the cost of time, then the cost index would be low. With zero cost of time it would be zero and the FMS would fly the aircraft at Mach for max range (MMR).

However if the cost of fuel was very cheap compared to the cost of time, then speed would be important and the CI would be high. For zero cost of fuel, the Cost Index would be 999 and the FMS would fly the aircraft just below MMO.

Best economics would be between these two speeds and would depend on the operator's cost structure and operating priorities. For more information on Cost Index see "Getting to Grips with the Cost Index"

4. PRE-FLIGHT PROCEDURES

Operation of the aircraft starts with the aircraft on the ground by aircraft maintenance, preparation and loading.

This part intends to highlight the impact of some ground operations on fuel consumption. Even if these operations enable only little savings in comparison with savings made during the cruise phase, ground staff has to be sensitive to them and should get into good habits.

This part is divided into seven different sections:

- Center of gravity position
- Excess Takeoff weight
- Flight Planning
- Ways of taxiing to save fuel
- Auxiliary Power Unit
- Fuel Tankering
- Aerodynamic Deterioration

4.1 CENTER OF GRAVITY POSITION

4.1.1 INTRODUCTION

The gross weight is the sum of the dry operating weight, payload and fuel and acts as one force through the center of gravity (CG) of the aircraft. The balance chart allows the determination of the overall center of gravity of the airplane taking into account the center of gravity of the empty aircraft, the fuel distribution and the payload. It must be ensured that the center of gravity is within the allowable range referred to as the center of gravity envelope.

A more forward center of gravity requires a nose up pitching moment obtained through reduced tail plane lift, which is compensated for by more wing lift. This creates more induced drag and leads to an increase in fuel consumption. It is better to have the center of gravity as far aft as possible. As a rearward shift in CG position deteriorates the dynamic stability of the aircraft, the CG envelope defines an aft limit.

4.1.2 AUTOMATIC CENTER OF GRAVITY MANAGEMENT

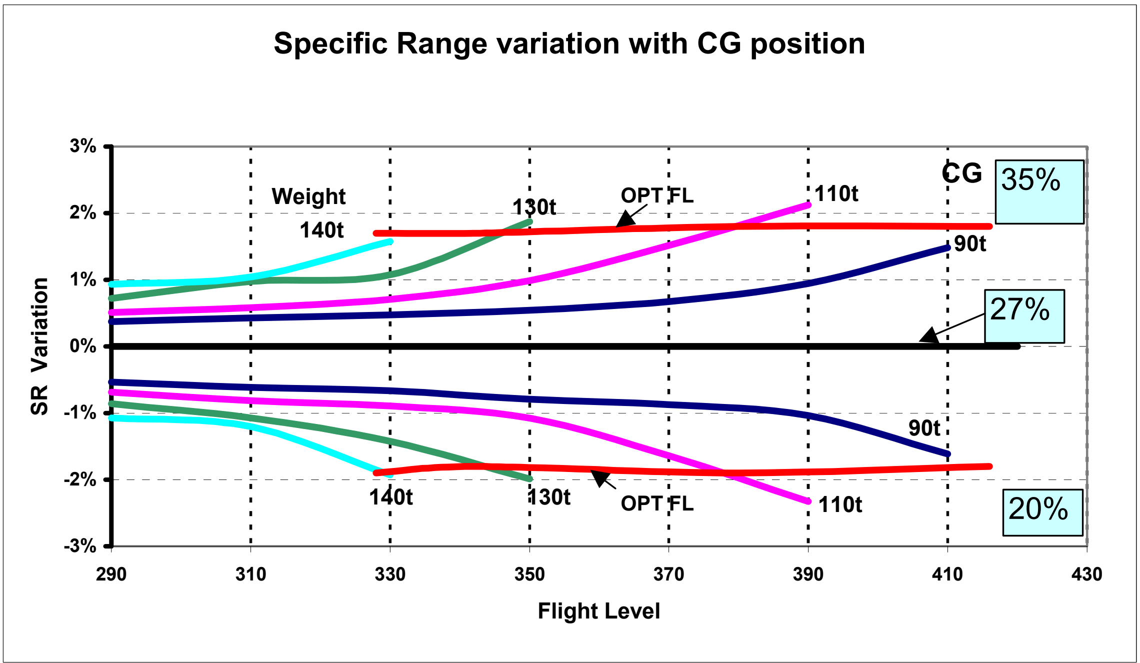
AIRBUS has created a trim tank transfer system that controls the center of gravity of the airplane. This system is installed on some A300 and A310 aircraft and all A330 and A340 aircraft. When an airplane with a trim tank is in cruise, the system optimizes the center of gravity position to save fuel by reducing the drag on the airplane. The system transfers fuel to the trim tank (aft transfer) or from the trim tank (forward transfer). This movement of fuel changes the center of gravity position. The crew can also manually select forward fuel transfer.

The Fuel Control and Management Computer (FCMC) calculates the center of gravity of the airplane from various parameters including input values (Zero Fuel Weight or Gross Take-off Weight and the associated CG) and the fuel tank contents. It continuously calculates the CG in flight. From this calculation, the FCMC decides the quantity of fuel to be moved aft or forward in flight to maintain the CG between the target value and 0.5% forward of the target band.

Usually one initial aft fuel-transfer is carried out late in the climb to bring the CG within this band. During the flight there are several smaller forward movements as the fuel burn moves the CG more aft. Finally a forward transfer is made as the aircraft nears its destination to bring the CG within the landing CG range.

4.1.3 INFLUENCE ON FUEL CONSUMPTION

The following graph shows the change in fuel consumption, expressed in terms of specific range (nm per kg of fuel), for both a Forward (20%) and an Aft (35%) CG position compared to a mid CG position of 27% at cruise Mach.



This graph, which is for the A310-203, shows the advantage of flying at aft CG. Also shown are the optimum altitude lines and these show the effects of CG to be constant at these altitudes, with almost no variation with aircraft weight. Other aircraft have similar shape curves with similar optimum altitude characteristics (except the A320 family). The following table summarizes the effect of CG on specific range at the optimum altitude :

Aircraft Type	Aft CG(35-37%)	Fwd CG(20%)
A300-600	+1.7%	-0.9%
A310	+1.8%	-1.8%
A330	+0.5%	-1.3%
A340	+0.6%	-0.9%

For the A300/A310 reference CG is 27% and aft CG is 35%.

For the A330/A340 reference CG is 28% and aft CG is 37%.

At maximum altitude, the change in fuel consumption given in the table is larger by up to 1%. However no benefit is obtained, as the specific range (SR) is lower at aft CG at maximum altitude than at mid CG at optimum altitude.

For aircraft that are not fitted with automatic center of gravity management, not all these advantages may be realized because of the normal forward and rearward shift of CG in flight due to fuel burn. In addition loading these aircraft at max fuel to an aft CG could prove difficult.

The **A320 family** does not show the same SR variation with CG as the other aircraft. The aft CG produces worst SR at FL290, crossing over to show an improvement at higher flight levels. The SAR variation is much smaller also. This is due to a complex interaction of several aerodynamic effects. The SAR can be considered effectively constant with CG position. Loading is therefore not critical for fuel economy for the A320 family.

In order to assess the overall impact of CG variation on fuel burn, it must be assessed on a complete sector. The following table shows increases in fuel consumed with a more forward CG. It is expressed as kg per 1000nm sector per 10% more forward CG for the max variation case (high weight, high flight level) with no in flight CG shift. The fuel increment in kg is also given for the Forward (20%) position, compared with the Aft (35 or 37%) position, for a typical sector.

Fuel Burn Increase with a more Forward CG

Aircraft types	Fuel increment KG/1000nm/10%CG	Typical Sector distance (nm)	Fuel increment per sector (kg)
A300-600	240	2000nm	710
A310	110	2000nm	330
A319/A320/A321	Negligible	1000nm	Negligible
A330-200	70	4000nm	480
A330-300	90	4000nm	600
A340-200	90	6000nm	900
A340-300	80	6000nm	800
A340-500	150	6000nm	1550
A340-600	130	6000nm	1300

4.2 TAKEOFF WEIGHT

4.2.1 INTRODUCTION

Another way to save fuel is to avoid excess take-off weight, which consists of the operating empty weight of the aircraft plus the payload plus the fuel.

In addition accurate knowledge of weight is an important factor needed to ensure that fuel burn predictions are met. This gives pilots confidence in the flight plans thus reducing the tendency to carry excess fuel.

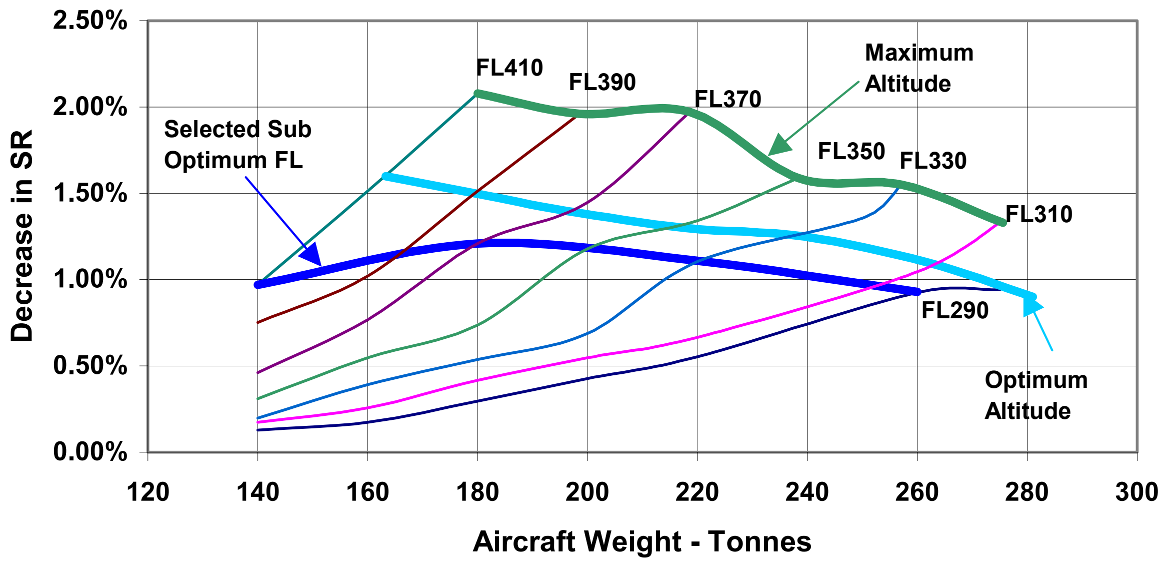
4.2.2 OVERLOAD EFFECT

The specific range, flying at given altitude, temperature and speed depends on weight. The heavier the aircraft, the higher the fuel consumption.

In addition, fuel savings can be made during climb since the aircraft would reach its optimal flight level earlier if it were lighter.

The effect of overloading with respect to the in-flight weight is shown on the following graph, for an excess load of 1% of MTOW (2600kg) in cruise for an A340-313 This shows the increase in specific range penalty with both weight and altitude. Maximum and optimum altitudes are shown together with selected sub optimum flight levels representing the choice of a FL below the Optimum instead of above it. For example, at 220t the optimum altitude is just under FL 350. If we select FL 330 1% extra MTOW will decrease the specific range by just under 1.2%

Specific Range Penalty for Excess Weight of 1% MTOW
A340-313 ISA MN 0.82



The characteristic curves for the other aircraft types have a similar shape. Calculating the weight effect on specific range on all Airbus aircraft in accordance with the lower boundary of typical flight levels gives an average reduction of 1% of SR for a weight increase of 1% of Maximum Take-off Weight. The scatter in this value is generally within .2%.

At the higher altitudes, obtainable at lower weights, the previous picture shows that the SR reduction can increase to 1.5%

Overloading affects not only the trip fuel but also the reserves and requires increased fuel uplift for a specific mission. The following table shows the effect of 1 tonne/1000nm and also 1% of basic MTOW for a typical sector, both at optimum altitude, assuming maximum passengers and some freight.

Aircraft types	Payload	Weight Increase	Stage	Fuel Penalty 1000nm/t	Fuel penalty per sector	Extra Reserves
A300-600	31000 kg	1705 kg	2000 Nm	93 kg	320 kg	100 kg
A310-300	26560 kg	1500 kg	2000 Nm	59 kg	240 kg	90 kg
A318	14650 kg	640 kg	1000 Nm	31 kg	30 kg	30 kg
A319	13000 kg	590 kg	1000 Nm	38 kg	50 kg	40 kg
A320	17200 kg	735 kg	1000 Nm	43 kg	60 kg	45 kg
A321	19100 kg	890 kg	1000 Nm	48 kg	55 kg	50 kg
A330-200	29800 kg	2300 kg	4000 Nm	49 kg	460 kg	100 kg
A330-300	29800 kg	2300 kg	4000 Nm	47 kg	440 kg	100 kg
A340-200	29000 kg	2535 kg	6000 Nm	74 kg	1130 kg	170 kg
A340-300	29000 kg	2535 kg	6000 Nm	87 kg	1330 kg	230 kg
A340-500	35700 kg	3680 kg	6000 Nm	64 kg	1410 kg	210 kg
A340-600	42250 kg	3650 kg	6000 Nm	65 kg	1420 kg	210 kg

Although the A320 family show considerably lower fuel burn penalties than the other aircraft, the total fuel penalty is of a similar order due to the high number of sectors per day. It can readily be seen that a 1% weight penalty has a significant impact on fuel costs when looked at on a yearly basis for a fleet of aircraft.

4.2.3 AIRCRAFT OPERATING WEIGHT

The operating empty weight of an aircraft is defined as the manufacturer's weight empty plus the operator's items. The latter include the flight and cabin crew and their baggage, unusable fuel, engine oil, emergency equipment, toilet chemicals and fluids, galley structure, catering equipment, seats, documents, etc.

The OEW of new aircraft, even in the same fleet, can vary significantly, due to specification changes, build differences and normal scatter. Also aircraft generally get heavier all through their operational life. This is due to repair schemes, service bulletins, equipment upgrades, dirt, rubbish and moisture accumulation and unnecessary equipment and supplies.

This variation in weight requires regular monitoring for flight planning purposes. In general most weight growth is inevitable and it cannot be controlled at the operational level. However the airline has to be sensitive to these problems and efforts have to be made in order to avoid excess weight, such as dirt, rubbish and unnecessary equipment and supplies. It should be noted that 100kg of excess weight requires an additional 5000kg of fuel per year per aircraft.

4.2.4 PAYLOAD

The most important part of the take-off weight from an airlines point of view is the payload (passengers and freight). Generally the weight of passengers, carry-on baggage and checked bags are defined in the operating rules by the authorities such as the JAA or the FAA. Most operators use standard weights although other values may be used if they can be statistically demonstrated through surveys. In general there is not much an operator can do to change the situation. However they should be aware of the rules and their validity. If the weights do not seem appropriate then an operator should consider conducting a survey.

As each freight consignment is weighed, the only influence it can have on fuel economy is its location and hence the aircraft CG.

4.2.5 EMBARKED FUEL

Fuel is loaded onto the aircraft to be used as follows:

1. Start-up Fuel
2. Taxi Fuel
3. Trip Fuel
4. Reserve Fuel
5. Fuel for Transportation
6. APU Fuel

In order to avoid unnecessary fuel weight, the flight must be planned very precisely to calculate the exact fuel quantity to be embarked. Flight planning should be based on aircraft performance monitoring by taking into account performance factors derived from specific range variations. In addition the planning should be based on the appropriate optimized techniques using the best achievable routing and flight levels.

More detailed information on this subject is given later in this brochure.

4.3 FLIGHT PLANNING

The fundamental requirement for achieving fuel economy and reduction of operating costs is a quality Flight Planning System.

A good flight planning system will produce an **optimized route**, in terms of track, speeds and altitudes, which meets the operator's economic criteria. This track and vertical profile must be normally achievable in operation, given the constraints of ATC, climb rates, descent rates, etc.

Climb, cruise and descent **techniques** and cruise **flight levels** should be optimized in accordance with the operator's criteria, for both the sector and the diversion. This is covered in much more detail in this brochure.

It will be based on **good quality data** (temperature, wind, aircraft weight, payload, fuel uplift, etc)

It will be use the **correct aircraft performance** and will include an individual aircraft performance factors derived from an ongoing aircraft performance monitoring (APM) program (see "Getting to Grips with Aircraft Performance Monitoring").

Having established the climb, cruise and descent techniques, it should be verified from time to time that the aircrews are using these techniques

The fuel **reserves** will be based on a policy that aims at obtaining the minimum values required within the regulations.

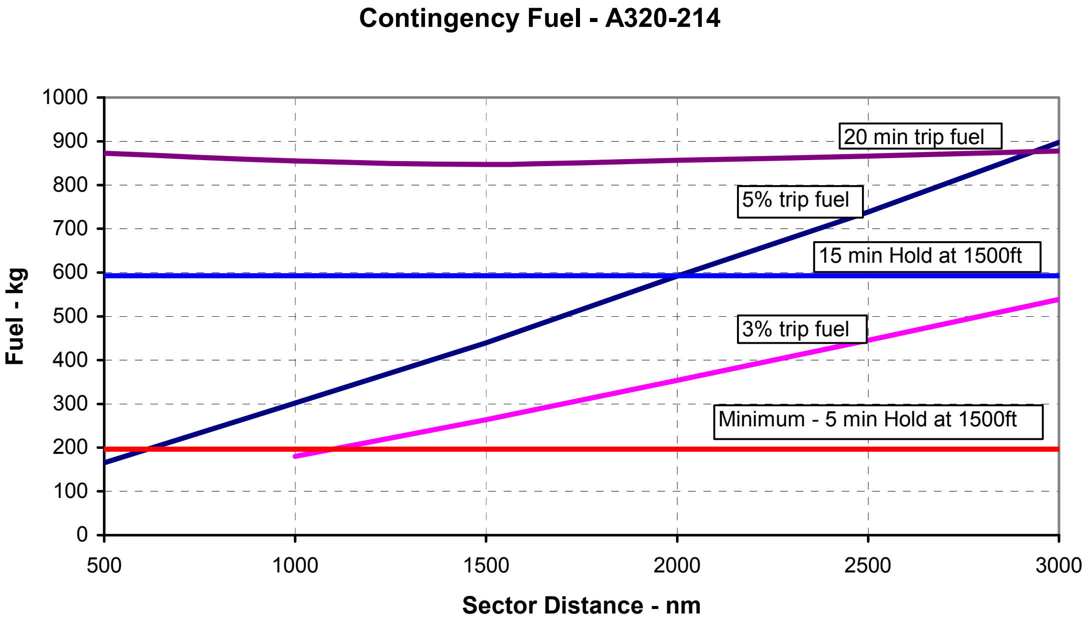
Within JAR OPS, there are several definitions of **Contingency** fuel, depending on diversion airfields, fuel consumption monitoring, etc. Full details can be found in "Getting to Grips with Aircraft Performance", but briefly the fuel is the greater of two quantities:

1. 5 minutes hold fuel at 1500 feet above destination at ISA

2. One of the following quantities:
   5% of trip fuel,
   3% of trip fuel with an available en route alternate airport
   15 minutes hold fuel at 1500 feet above the destination at ISA
   20 minutes trip fuel**,** based upon trip fuel consumption.

The last 3 options require airworthiness approval and the last 2 options require fuel consumption monitoring with fuel based on results. What we can conclude is that depending on the flight distance, there is a lowest contingency fuel.

The following graphs show the different contingency fuel quantities for different distances for an A320.



The graphs for other members of the A320 family are similar and indicate that below about 500nm, the contingency fuel is set by the minimum 5-minute hold value. Above about 1000nm, contingency fuel can be reduced to 3% of trip fuel if there is an en-route alternate available. If not, reductions can be made above about 2000nm by using the 15-minute destination hold option, which always requires less fuel than the 20 minute trip fuel option.

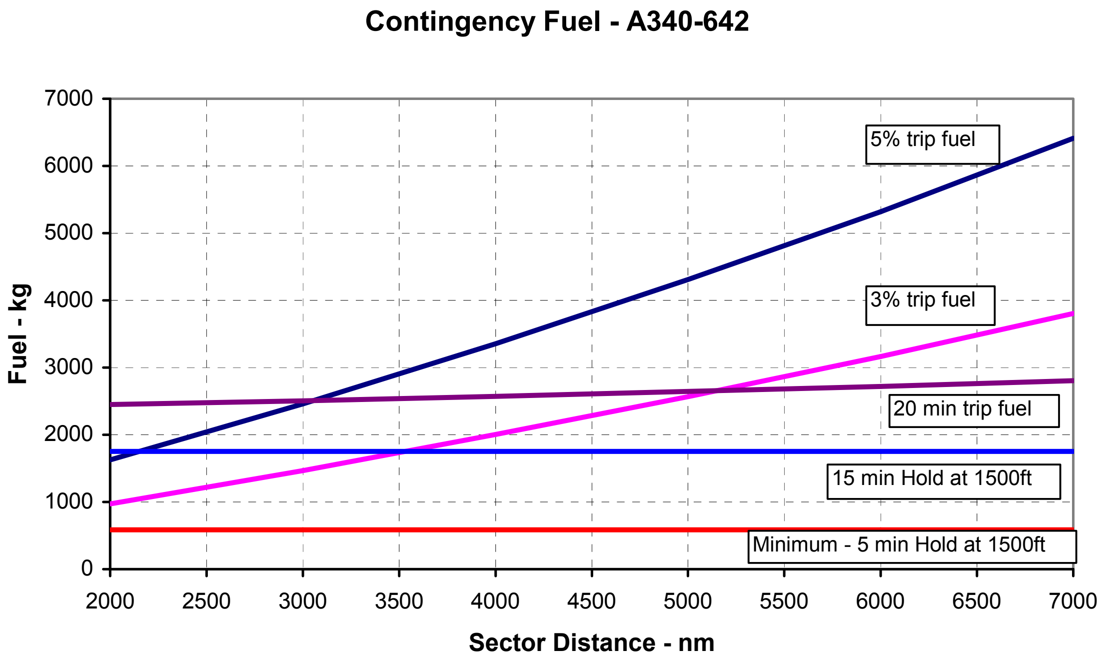
The graphs for the other aircraft show different characteristics because of their longer-range capability.

The A340-600 picture, on the following page, indicates that with no en-route alternate the 15-minute destination hold requirement enables the contingency fuel to be reduced above 2150nm. An en-route alternate will give more benefit until 3500nm, beyond which the 15-minute destination hold minimises the contingency fuel requirement. The A340-500 is similar.

The A300, A310, A330 and other A340's have slightly different critical distances as follows:

5% trip fuel/15-minute hold	1700 to 1900nm.
3% trip fuel/15-minute hold	2800 to 3200nm

However these will also vary with weight, winds, temperature, etc so the limiting reserve should always be checked. Each aircraft type will show critical sector distances beyond which a change in contingency policy will yield benefits.



One further method of reducing the contingency fuel is by using a Decision Point or **Redispatch** Procedure. This involves the selection of a decision point where the aircraft can either continue to the destination as the remaining fuel is sufficient, or it can reach a suitable proximate diversion airport. More details are given in "Getting to Grips with Aircraft Performance".

To minimize the **alternate** fuel, the alternate airports should be chosen as near as possible to the destination.

Both the JAA and FAA do not require the alternate fuel reserve in certain cases, depending on meteorological conditions and the suitability of the airport. More details are given in "Getting to Grips with Aircraft Performance".

Another part of the reserves is the **extra fuel**, which is at the Captain's discretion.

There are many reasons why this extra fuel is necessary. It could be due to uncertain weather conditions or availability of alternate and destination airfields, leading to a probability of re-routing. However it is often due to lack of confidence in the flight planning and the natural desire to increase reserves.

This is the one area where a significant impact can be made through accurate flight planning. With this in place, the aircrew will see that the flight plans fuel burns are being achieved in practice. They will realize that the planned reserves are adequate and that there is no need for more.

4.4 TAXIING

Good estimate of taxi times are required. Actual times need to be monitored and standard estimates changed as necessary. Jet engine performance is optimised for flight conditions, but all aircraft spend considerable time on the ground taxiing from the terminal out to the runway and back. This time has increased due to airport congestion, and increased airport size. This all leads to a waste of precious time and fuel.

Only using one engine for taxiing twin-engine aircraft, or two engines for four-engine aircraft can give benefits in fuel burn. Such procedures need to be considered carefully, and operators have to define their field of application.

Airbus provides standard procedures in the Flight Crew Operating Manual (FCOM) for such operations. The following factors regarding one or two engine out taxi should be considered carefully prior to its incorporation in the operators standard operating procedures:

1. This procedure is not recommended for high gross weights
2. This procedure is not recommended for uphill slopes or slippery runways
3. No fire protection from ground staff is available when starting engine (s) away from the ramp
4. Reduced redundancy increases the risk of loss of braking capability and nose wheel steering.
5. FCOM procedures require not less than a defined time (from 2 to 5 minutes depending on the engine) to start the other engine(s) before take off. On engines with a high bypass ratio, warm-up time prior to applying maximum take off thrust has a significant effect on engine life.
6. Mechanical problems can occur during start up of the other engine(s), requiring a gate return for maintenance and delaying departure time.
7. FCOM procedures require APU start before shutting down the engine after landing, to avoid an electrical transient.
8. FCOM procedures require not less than a defined time before shutting down the other engine(s) after landing. On engines with a high bypass ratio, the cool-down time after reverse operation, prior to shut down has a significant effect on engine life.
9. If an operator decides to use one or two engine out taxi, then FCOM recommendations about which engine(s) to use should be followed.

As engine-out taxi requires more thrust per engine to taxi and maneuver, caution must be exercised to avoid excessive jet blast and FOD. More thrust is necessary for breakaways and 180 degrees turns.

On twin-engine aircraft slow and/or tight taxi turns in the direction of the operating engine may not be possible at high gross weight.

Single engine taxi may also be considered at low weights to avoid excessive use of the brakes to control the acceleration tendency with all engines. This brake use would be detrimental to carbon brake life.

The following table gives an indication of the advantages of engine out taxi for 8 of the 12 minutes total taxi time, leaving 4 minutes warm up time.

Fuel savings with Engine out taxi

Aircraft types	12 minutes taxi (all engines)	12 minutes taxi (8 with engine out)	Engine Out taxi savings
A300-600	300kg	200kg	100kg
A310	240kg	160kg	80kg
A318	120kg	80kg	40kg
A319	120kg	80kg	40kg
A320	138kg	92kg	46kg
A321	162kg	108kg	54kg
A330	300kg	200kg	100kg
A340-200/300	300kg	200kg	100kg
A340-500/600	420kg	280kg	140kg

For engine out or all engines taxi, the use of a slow taxi speed costs fuel and time. A burst of power should be used to get the aircraft to taxi speed, then the power should be reduced to idle. However 30kt should not be exceeded.

4.5 FUEL FOR TRANSPORTATION

The normal message regarding fuel burn is that it is more economical to carry the minimum amount required for the sector. However there are occasions when it is economic to carry more fuel. This is when the price of fuel at the destination airfield is significantly higher than the price at the departure airfield.

However, since the extra fuel on board leads to an increase in fuel consumption the breakeven point must be carefully determined.

K is the **transport coefficient**:

$$K = \frac{\Delta TOW}{\Delta LW}$$

The addition of one tonne to the landing weight, means an addition of K tonnes to the take-off weight.

For example, if K=1.3 and 1300 kg fuel is added at the departure, 1000 kg of this fuel amount will remain at the destination. So carrying one tonne of fuel costs 300 kg fuel more.

<u>The extra-cost of the loaded fuel at departure is</u>

Fuel weight x departure fuel price ($\Delta TOW \times P_d = \Delta LW \times K \times P_d$)

<u>The cost saving of the transported fuel is</u>

Transported fuel x arrival price ($\Delta LW \times P_a$)

<u>The cost due to a possible increase in flight time is</u>

Flight time increase x cost per hour ($\Delta T \times C_h$)

It is profitable to carry extra fuel if the cost saving exceeds the extra fuel loaded cost plus the extra time cost.

$$(\Delta LW \times P_a) > (\Delta LW \times K \times P_d) + (\Delta T \times C_h)$$

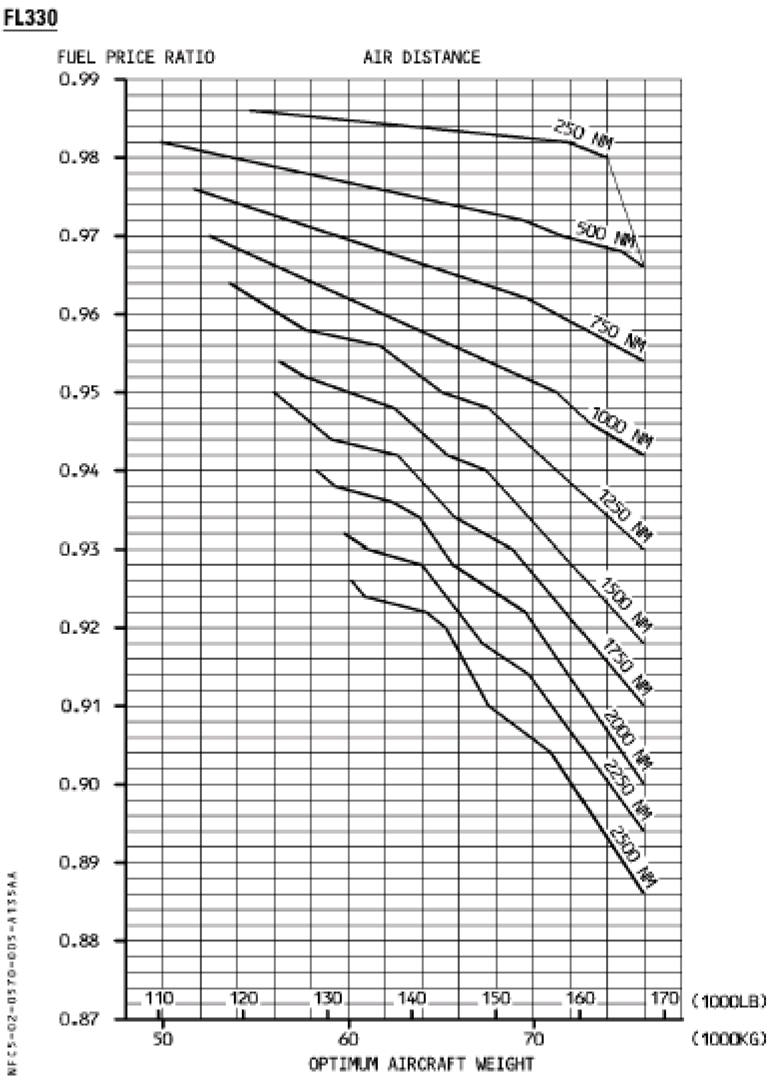
That is to say:

$$\Delta LW\ (P_a - K \times P_d) - (\Delta T \times C_h) > 0$$

Therefore, if $\Delta T=0$, it is profitable to carry extra fuel if the arrival fuel price to departure fuel price ratio is higher than the transport coefficient K.

$$\frac{P_a}{P_d} > K$$

Thus carrying extra fuel may be of value when a fuel price differential exists between two airports. Graphs in the FCOM assist in determining the optimum fuel quantity to be carried as a function of initial take-off weight (without additional fuel), stage length, cruise flight level and fuel price ratio. The following graph is an example for an A320.



However the needs for accurate fuel planning is necessary to avoid arriving at the destination airport overweight. This could result in the economic benefit being eroded or negated due to extra hold time or circuits.

4.6 AUXILIARY POWER UNIT

The Auxiliary Power Unit (A.P.U.) is a self-contained unit which makes the aircraft independent of external pneumatic and electrical power supply and environmental conditioning.

A.P.U. fuel consumption obviously represents very little in comparison with the amount of fuel for the whole aircraft mission. Nevertheless, operators have to be aware that adopting specific procedures on ramp operations can help save fuel and money.

On the ground, A.P.U. fuel consumption depends on the A.P.U. type load and the ambient conditions. The minimum is when the APU is in the RTL(ready to load) condition. As additional loads, such as Electrical Loads(EL) and Environmental Conditioning System (ECS), are connected, the fuel consumption increases as shown in the following table (ISA, SL conditions).

Aircraft Type	APU Model	RTL	RTL Max EL	Min ECS Max EL	Max ECS Max EL
A320 family	36-300	70 kg/hr	85 kg/hr	105 kg/hr	125 kg/hr
A320 Family	131-9A	75 kg/hr	95 kg/hr	115 kg/hr	125 kg/hr
A330, A340	331-350	120 kg/hr	140 kg/hr	175 kg/hr	210 kg/hr
A340-500/600	331-600	160 kg/hr	180 kg/hr	225 kg/hr	290 kg/hr

A.P.U. specific procedures to save fuel have to be defined by the operators. One extra minute of A.P.U. operation per flight at 180 kg/hr fuel flow, means an additional 3000 kg per year per aircraft. This will also result in increased maintenance costs.

They have to choose between using ground equipment (Ground Power Unit, Ground Climatisation Unit, Air Start Unit) and the A.P.U. This choice depends on several parameters and each operator needs to determine the benefits at each airport and at each turnaround.

Such parameters can include length of turnaround, ambient conditions, cost of ground connections, time delay to get connected, suitability and quality of ground equipment, passenger load, local noise restrictions, etc.

For a **long turnaround** or **night stop** the G.P.U. is the best choice as time considerations are not prevailing. It saves both fuel and A.P.U. life. So operators are advised to use ground equipment if of a good quality, and to try to conclude agreements with airport suppliers to get preferential prices.

However, for a **short turnaround** (45 minutes on average), the use of A.P.U. may be preferable to limit A.P.U. start cycles and improve reliability, even if it is not fully used during the turnaround. It is better to operate with A.P.U. at RTL than to shut it down and perform a new start cycle soon after shut down. Lack of suitable ground power may also require the use of APU. The use of APU may also be preferable to avoid excessive hook up charges or to reduce turnaround time.

Some airport regulations restrict the use of the APU to a defined time prior to departure time and after the arrival.

For **extremely short turnarounds**, complete engine shut down would have a cyclic cost impact, and therefore the turnaround could be made without APU. However a main engine can sometimes not meet the ECS demand in high load conditions (hot days).

The disconnection of ground equipment supplies and the start of A.P.U. must be coordinated with A.T.C. pushback/slot requirements. A **one-minute anticipation** in each A.P.U. start will lead to a significant amount of fuel saving during a year (2000 to 4000 kg depending on A.P.U. types).

Engine start up should also, if possible, be carefully planned in conjunction with A.T.C. If pushback is delayed, it is preferable to wait and use A.P.U. for air conditioning and electrical requirements. Engine start time is critical, and the engines should not be started until ready to go.

The following table assuming typical engine fuel flows, shows extra fuel consumption by using one engine instead of the A.P.U. for 1 minute, assuming maximum electrical load and minimum ECS:

Extra fuel when using Engine instead of APU

Aircraft Type	A.P.U. type	Engine FF kg/hr/eng	APU FF kg/hr	Extra Fuel for 1 minute
A300 GE	331-250	520	150kg	6kg
A310 GE	331-250	520	150kg	6kg
A320 family CFM	36-300	300	105kg	3kg
A330 GE	331-350	520	175kg	6kg
A330 RR	331-350	720	175kg	9kg
A340 CFM	331-350	300	175kg	2kg
A340 RR	331-600	480	275kg	4kg

In overall economic terms, the benefits of APU operation are not just confined to fuel usage. The hourly maintenance costs of an APU are cheaper than the aircraft powerplant, so reducing ground running time on the engines can significantly reduce the operating costs.

4.7 AERODYNAMIC DETERIORATION

Some of the most severe penalties in terms of fuel consumption are caused by increased drag resulting from poor airframe condition. Normal aerodynamic deterioration of an aircraft over a period of time can include the incomplete retraction of moving surfaces, damaged seals on control surfaces, skin roughness and deformation due to bird strikes or damage caused by ground vehicles, chipped paint, mismatched doors and excessive gaps. Each deterioration incurs a drag increase, and this increased drag is accompanied by increased fuel consumption.

This subject is covered fully in the brochure "Getting Hands-On Experience with Aerodynamic Deterioration".

The following table gives the highest deterioration effect in each category for the three aircraft families as increased sector fuel consumption in Kg, based on typical utilization figures.

Category	Condition	A300/310	A320 Family	A330/340
Misrigging	Slat 15mm	90	60	270
Absence of Seals	Flap (chordwise)	30	14	90
Missing Part (CDL)	Access Door	50	13	150
Mismatched Surface	Fwd Cargo Door 10mm step for 1m	20	11	80
Door seal leakage	Fwd Pax Door 5cm	2	1	5
Skin Roughness	1 m^2	21	13	105
Skin Dents	Single	2	1	2
Butt joint gaps	Unfilled	0.2	0.1	0.6
Butt Joint Gaps	Overfilled	3	2	7
External Patches	1 m^2 3mm high	6	3	16
Paint Peeling	1 m^2 leading edge slat	12	8	57
	Sector Distance	2000nm	1000nm	4000/6000nm

5. IN FLIGHT PROCEDURES

When an aircraft arrives at the end of the runway for take-off, it is the flying techniques (speed, altitude, configuration, etc) that have the biggest influence on fuel economy. Disciplined flight crews adhering to a flight plan based on the operator's priorities can save much fuel and/or costs.

This part intends to give recommendations to flight crews on the means to save fuel during the flight. It reviews the different phases of the flight, that is to say:

- Take-off and Initial Climb
- Climb
- Cruise
- Descent
- Holding
- Approach

5.1 TAKE-OFF AND INITIAL CLIMB

5.1.1 INTRODUCTION

There are many variations in take-off technique that can directly affect the fuel burn. In general the effects are very dependent on the airframe/engine combination as well as aircraft weight, airfield altitude and temperature. The following fuel effects are representative values.

5.1.2 BLEEDS

For take-off, full bleeds can be used or one can consider selecting packs off or APU bleed on to improve take-off performance. Selecting packs off **without APU** will also improve fuel burn. The normal procedure would then be to select pack 1 on after climb thrust is selected and pack 2 on after flap retraction. This has the effect of reducing fuel burn by 2-3 kg on an A320 increasing to 5-10 kg on an A340-500/600.

With APU bleed the engine fuel burn will be decreased by the same amount. However with APU used from pushback with 12minutes taxi, the additional APU fuel burn is 30kg for an A320 and 60-70kg for an A340.

In economic terms, the APU fuel and maintenance cost is largely offset due to decreased engine maintenance costs bleeds off (higher flex temp).

5.1.3 CONFIGURATION

This effect is very dependent on the variables mentioned in the introduction, plus the choice of VR and V2. However the trend is always the same , with high flap/slat configurations (more extended) using more fuel than the lowest setting. Typical penalties/takeoff of higher flap settings compared with the low flap settings Conf 1+F are shown below (note that for the A300/A310 Conf 1+F, Conf 2 and Conf 3 corresponds to the Flap 0,15 and 20 configuration respectively).

Aircraft	Conf 2	Conf 3
A300/A310	1- 5kg	15kg
A320	3-5kg	8-13kg
A330	12kg	24kg
A340	30kg	50kg

These figures assume Full take-off thrust. The advantage of Conf 1+F increase with reduced power take-offs.

5.1.4 SPEEDS

During a non limiting full power take-off, the use of the higher speeds appropriate to flex thrust instead of optimized speeds appropriate to the actual temperature can reduce the fuel burn by up to 8kg.

5.1.5 FLEX THRUST

Compared to a full thrust take-off, flex thrust will generally increase fuel burn. The increased time at low level offsets the slight reduction in fuel flow induced by the lower thrust. Typical increases are as follows:

Aircraft	Conf 1+F	Conf 2	Conf 3
A300/A310	10kg	10kg	10kg
A320	1kg	5kg	5kg
A330	0	0	0
A340	5kg	20kg	25kg

5.1.6 NOISE FLIGHT PATHS

The effect of an ICAO type A noise flight path, with climb thrust selected at 800ft and clean up delayed until 3000ft is generally to increase fuel burn compared to the standard take-off with power reduced at 1500ft. The actual distance to a fixed height, say 5000ft, varies very little with configuration. The main effect is the different altitude – speed history experienced by the engines. Typical values are as follows:

Aircraft	Conf 1+F	Conf 2	Conf 3
A320	-4kg	+5kg	+2kg
A330	+100kg	+100kg	+115kg
A340	+90kg	+130kg	+125kg

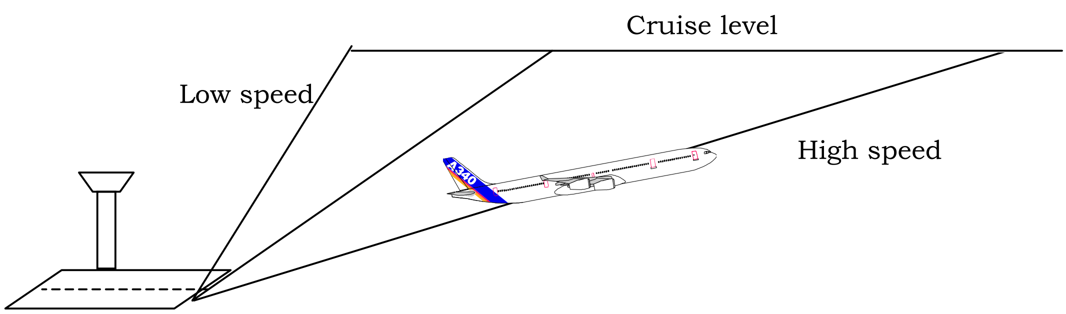
5.1.7 COURSE REVERSAL

In the event that a course reversal is required after take-off, then much distance can be saved using a lower initial climb speed. Suppose ATC require an aircraft to maintain runway heading to 6000ft. A lower climb speed will achieve this altitude earlier and thus reduce the ground distance and fuel burnt.

5.2 CLIMB

5.2.1 INTRODUCTION

Depending on speed laws, the climb profiles change. The higher the speed, the lower the climb path, the longer the climb distance.



Climb profiles

Climbs are normally performed in three phases on a constant IAS/Mach climb speed schedule at max climb thrust, as follows:

- 250 KT indicated air speed (IAS) is maintained until flight level 100, then the aircraft accelerates to the chosen indicated air speed (e.g. "300kts);
- constant indicated air speed is maintained until the crossover altitude;
- constant Mach number is maintained until top of climb;

The crossover altitude is the altitude where we switch from constant IAS climb to the constant Mach number climb. It only depends on the chosen IAS and Mach number, and does not depend on ISA variation.

During climb, at constant IAS, the true air speed (TAS) and the Mach number increase. Then, during climb at constant Mach number, the TAS and the IAS decrease until the tropopause.

To correctly evaluate the effects of climb techniques, climb and cruise flight must be viewed in relation to each other. A short climb distance for example extends the cruise distance; a low climb speed requires more acceleration to cruise speed at an unfavourable high altitude. One has therefore to consider sectors that cover acceleration to climb speed, climb, acceleration to cruise speed and a small portion of the cruise to the same distance.

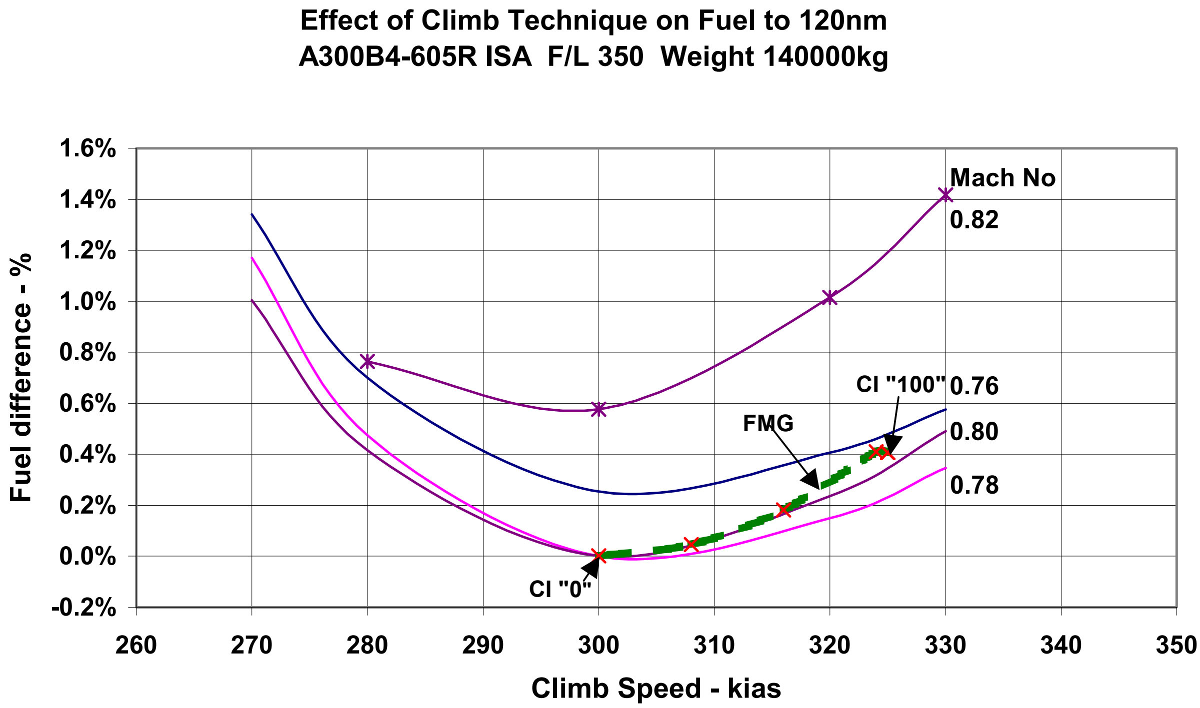
5.2.2 THE EFFECT OF CLIMB TECHNIQUE ON FUEL BURN

This evaluation has been made for all Airbus types, based on a climb to 35000ft, acceleration and cruise to a fixed distance. The assumed cruise speed was 0.78 for the A320 family and 0.8 for the rest.

The reference climb technique is the standard technique given in each FCOM, and is summarized below:

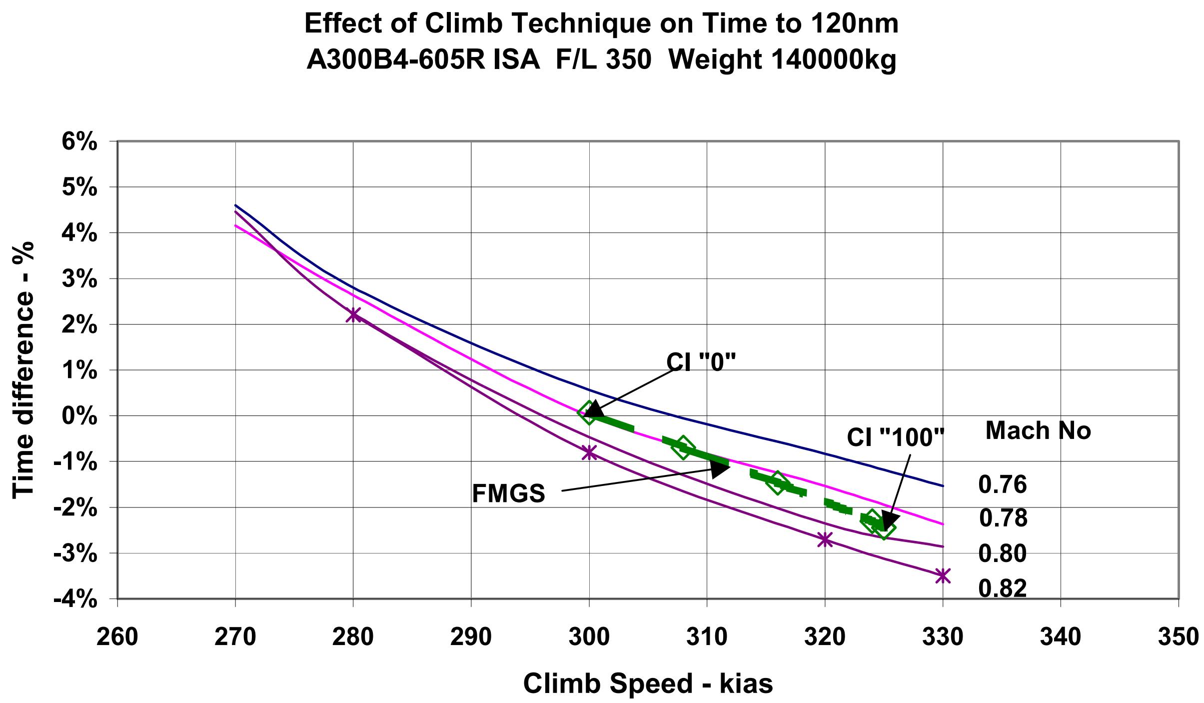
Aircraft types	Speed law
A300-600	250kts/300kts/M0.78
A310 (GE)	250kts/300kts/M0.79
A310 (PW)	250kts/300kts/M0.80
A318/A319/A320/A321	250kts/300kts/M0.78
A330	250kts/300kts/M0.80
A340-200/300	250kts/300kts/M0.78
A340-500/600	250kts/320kts/M0.82

The following chart shows the variation of fuel burn with climb technique over a given climb + cruise distance.



This shows that there is an optimum climb speed and max climb Mach number that produces the lowest fuel burn. This happens to be the standard technique (300kt/0.78). Climbing at 320kt/0.82 will burn 1% more fuel.

However the following chart shows that this is obtained at the **expense of time.**



This time difference plot has the same characteristics for all Airbus aircraft, with the best time being obtained at the highest climb speed and max climb Mach number. Note that although a slow climb speed gets the aircraft to cruise altitude earlier, this requires more acceleration to cruise speed and more cruise to a given distance, making it slower overall.

The fuel difference plot characteristics vary with aircraft type. The A310, A321 and A330 show similar characteristics to the A300 with a best fuel climb speed of about 290 to 300 knots.

The A318, A319 and A320 show better fuel burn at the lower speed range (260 to 280 knots)

The A340 shows better fuel burn at the higher speed range (310-330 knots).

The A310 and A340 are similar to the A300 in showing minimum fuel at a max climb Mach number of 0.78. In fact 0.8 is better for the A340-500/600.

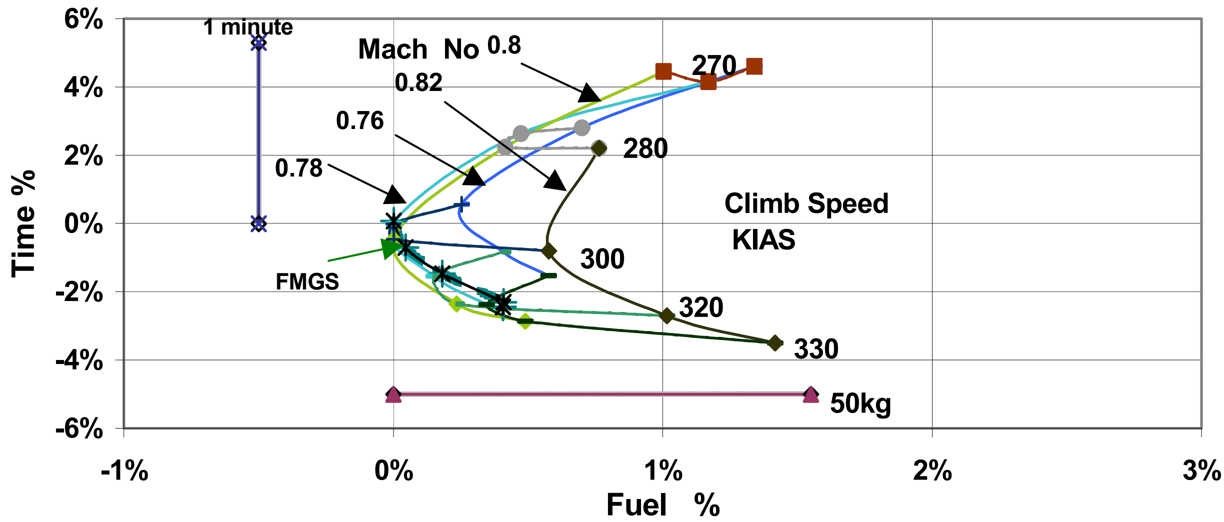
However the A320 family and A330 benefit from the lower Mach No of 0.76.

Thus the A320 family benefits from low climb speeds and the A340 from high climb speeds. This difference arises from the different behavior during climb of twin-engine and four-engine aircraft. Indeed, twin-engine aircraft have a higher thrust than four engine aircraft, as they must satisfy some take-off climb requirements with only one engine operative, compared with 3 engines operative on the quads. This enables them to have a higher rate of climb than four engine aircraft and reach cruise flight levels quicker.

5.2.3 CORRELATION OF FUEL BURN & TIME WITH CLIMB TECHNIQUE

The following chart shows the differences in fuel and time to climb and cruise to a fixed distance with varying climb speed and max climb Mach number relative to the standard technique.

Effect of Climb Technique on fuel and time to 120nm
A300B4-605R ISA F/L 350 Weight 140000kg

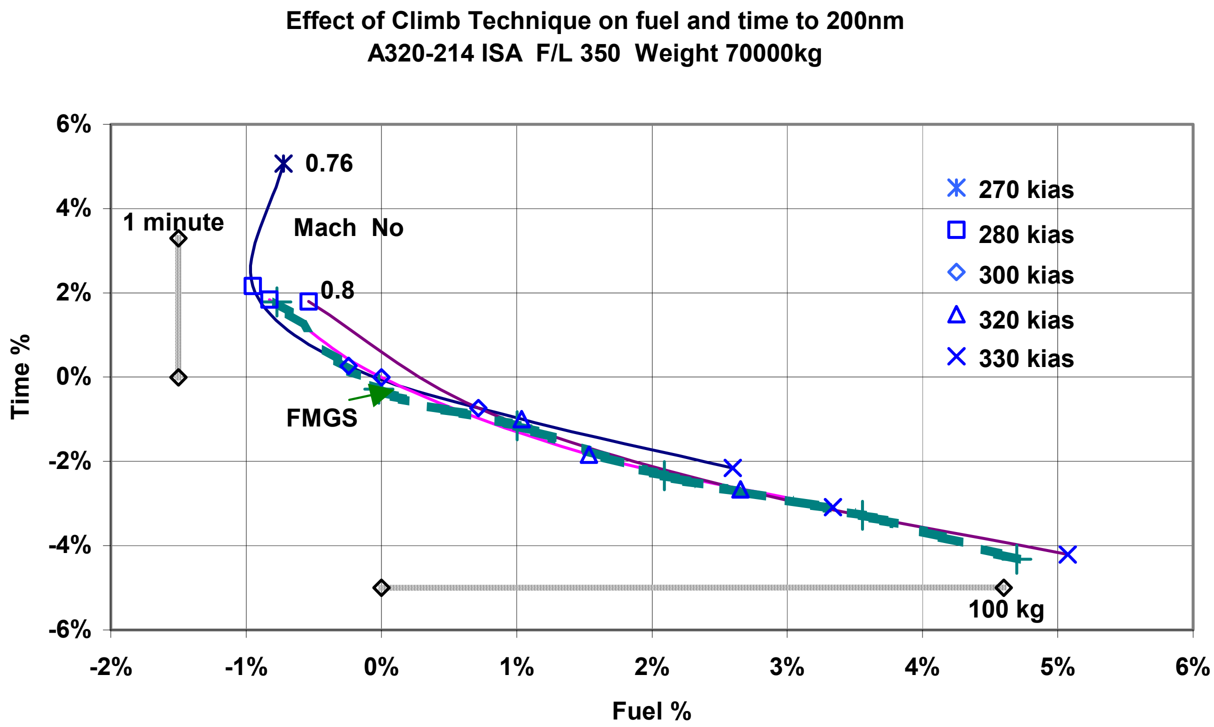


This chart shows that the fastest technique (330/0.82) uses the least time (-3.2%) and the most fuel (+1.5%) whereas the slowest technique (270/0.76) uses the most time (+4.5%) and nearly the most fuel (+1.4%). The least fuel is obtained using a 300/0.78 climb technique. Variation of climb technique can cause a total variation of 1.5% and climb time by 8% for this aircraft.

Also plotted on the charts are lines representing the speeds selected by the FMGS for various cost indices (CI). The left hand point of each line represents a CI of zero (fuel cost priority) and the right hand point represents a CI of 100 (flight time priority). It should be noted how the FMGS line approximates to the lower boundary of the time - fuel difference plot.

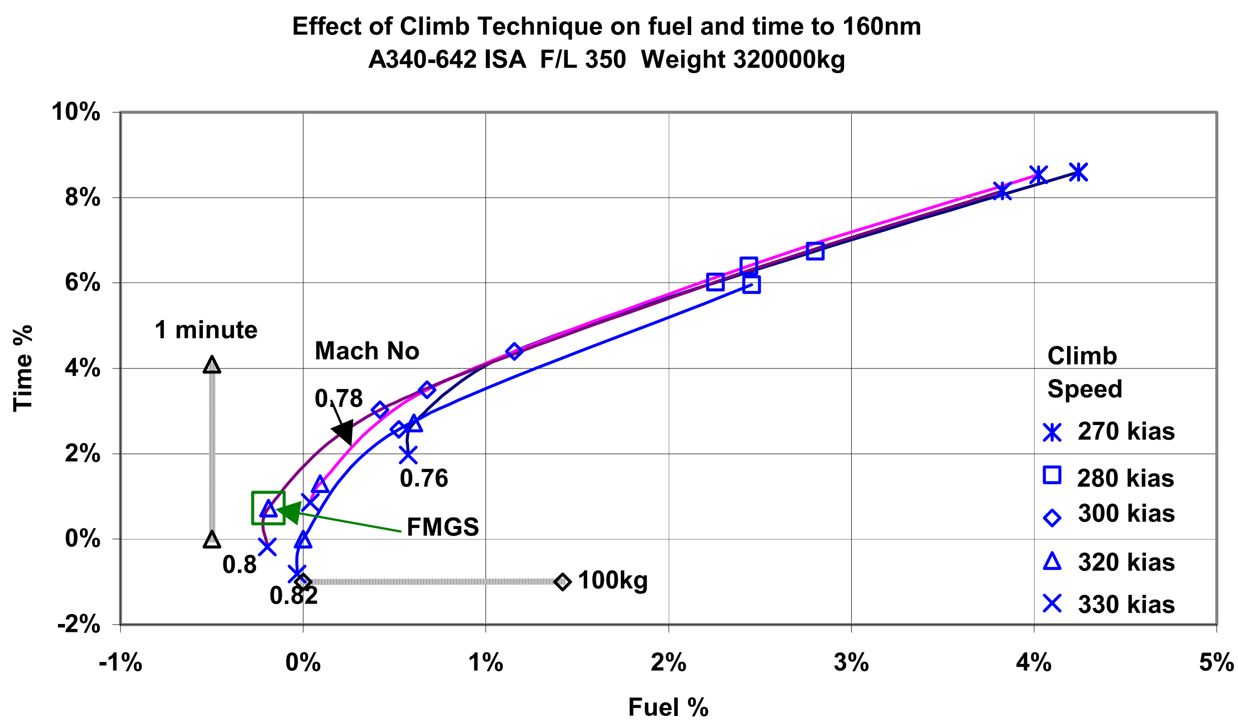
The chart on the following page is for the A320 and shows completely different characteristics.

The different mach numbers all coalesce together and the FMGS line forms the



common boundary. Climb speed increases from the left to the right. Least fuel is obtained using a 0.76/280 technique. Mach No has little influence, but increasing speed from 280 to 330kias decreases time by 6% and increases fuel by 6%.

Completely different characteristics are also shown in the next chart (A340-642).



This shows a common technique is good for both fuel burn and time. The optimum is 320/0.80. There is little Mach No effect, but reducing the speed to 270 kias will increase fuel by 4% and time by 8%. Because the optimum technique is good for both fuel and time, there is a single FMGS point for all cost indeces.

Earlier versions of the A340 showed that some marginal time benefit could be gained by climbing faster. However this would have affected the flight levels achieved. Consequently there is no variation of FMGS climb speed with cost index for all the A340 family.

Appendix A presents some examples of time - fuel charts for other Airbus aircraft.

5.2.4 CLIMB TECHNIQUE COMPARISON TABLES

The following tables show, for various Airbus aircraft, the climb time and fuel variations for a fixed distance, to FL 350, relative to a 300kias reference speed.

Effect of Climb Speed on Fuel

Aircraft	Climb Mach No.	∆Fuel – kg				
		270KT	280 KT	300 KT	320 KT	330 KT
A300	0.78	+40	+15	0	+5	+10
A310	0.79		+5	0	+5	+15
A318/A319/A320	0.78		-15	0	+30	+70
A321	0.78		-10	0	+25	+60
A330	0.80	+15	+5	0	+20	+35
A340–200	0.78	+45	+20	0	+10	+25
A340-300	0.78	+105	+50	0	-5	+20
A340-500/600	0.82		+135	0	-5	-10

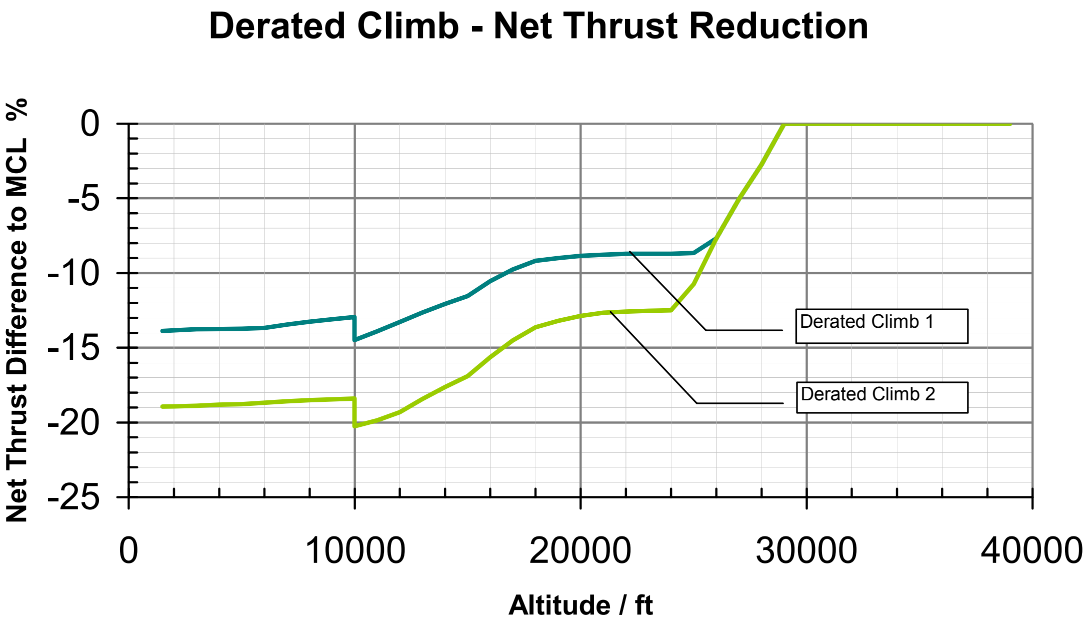
Effect of Climb Speed on Time

Aircraft	Climb Mach No.	∆Time – minutes				
		270KT	280 KT	300 KT	320 KT	330 KT
A300	0.78	+0.8	+0.5	0	-0.3	-0.4
A310	0.79		+0.5	0	-0.5	-0.6
A318/A319/A320	0.78		+0.5	0	-0.4	-0.8
A321	0.78		+0.8	0	-0.6	-1.0
A330	0.80	+0.9	+0.6	0	-0.4	-0.7
A340–200	0.78	+1.4	+0.8	0	-0.6	-0.8
A340-300	0.78	+1.5	+0.9	0	-0.6	-1.0
A340-500/600	0.82		+0.8	0	-0.6	-0.8

It can be seen from the tables how the optimum techniques are very dependant on the aircraft type, and that a 10kt climb speed change can have a significant impact.

5.2.5 DERATED CLIMB

In order to reduce engine maintenance costs, there are derated climb options available on the A330 and A340 aircraft. There are two levels of derate, D1 and D2. At a certain altitude the derate is washed out such that at Max Climb rating is achieved generally before 30000ft. The following shows a typical derate thrust variation picture, but this will vary with engine and temperature.



However this derate will result in more fuel and time required to reach the same distance. The effect is dependant on aircraft weight, temperature and cruise flight level. The following table gives some typical penalties in ISA conditions to 35000ft.

Aircraft	Weight (kg)	Derate D1		Derate D2	
		Fuel Increase	Time Increase	Fuel Increase	Time Increase
A330-203	190000	5kg	0.5 min	20kg	0.6 min
A330-223	190000	20kg	0.2 min	40kg	0.5 min
A330-343	190000	20kg	0.2 min	35kg	0.5 min
A340-212	240000	60kg	1.0 min	120kg	1.5 min
A340-313	240000	30kg	0.8 min	70kg	1.4 min
A340-313E	240000	40kg	1.0 min	140kg	1.4 min
A340-642	340000	60kg	0.6 min	120kg	1.0 min

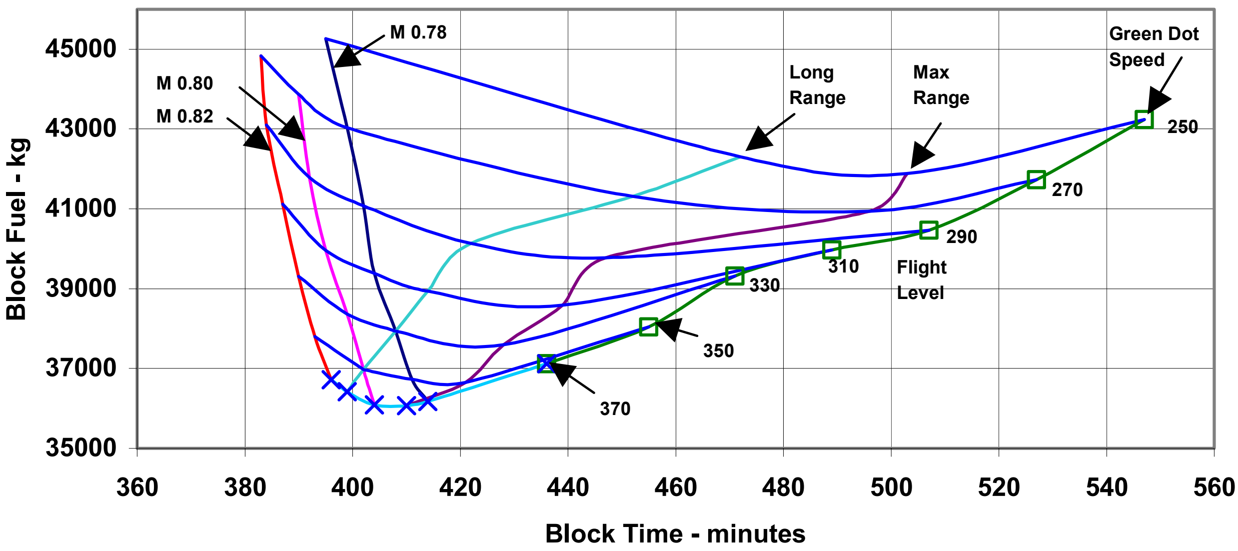
5.3 CRUISE

5.3.1 INTRODUCTION

The cruise phase is the most important phase regarding fuel savings. As it is the longest for long haul aircraft, it is possible to save a lot of fuel. So discipline must be exercised particularly in this phase.

The two variables that most influence cruise fuel consumption are the cruise speed (IAS or Mach Number) and the altitude or flight level. The following shows their influence on a single sector assuming standard climb and descent procedures.

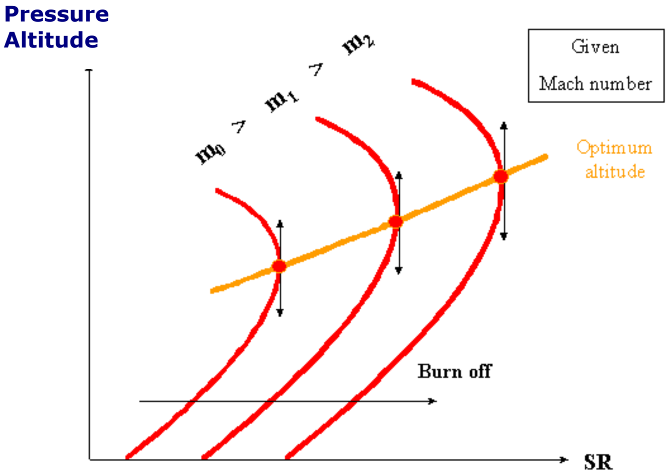
Block Fuel and Time for various Flight Levels and Mach numbers
A330-223 ISA 3000nm Payload 30000kg JAR Reserves



The correct selection of the cruise parameters is therefore fundamental in minimizing fuel or operating cost. This chart shows the normal laws that aircraft consume less fuel when flown slower or when flown higher. However there are limits to these laws. Flying lower than the maximum range speed will increase the block fuel, as will flying higher than an optimum altitude.

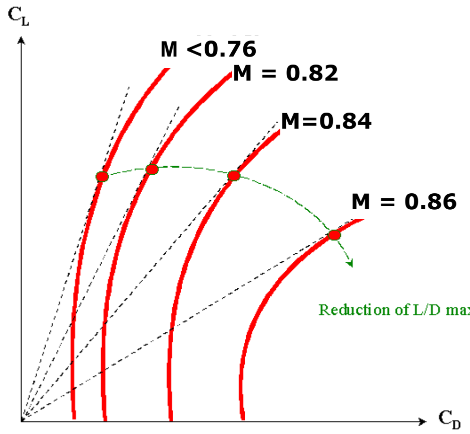
5.3.2 CRUISE ALTITUDE OPTIMISATION

In examining SR changes with the altitude at a constant Mach number, it is apparent that, for each weight, there is an altitude where SR is maximum. This altitude is referred to as "optimum altitude".



Optimum Altitude Determination at Constant Mach Number

When the aircraft flies at the optimum altitude, it is operated at the maximum lift to drag ratio corresponding to the selected Mach number.



High Speed Polar Curve

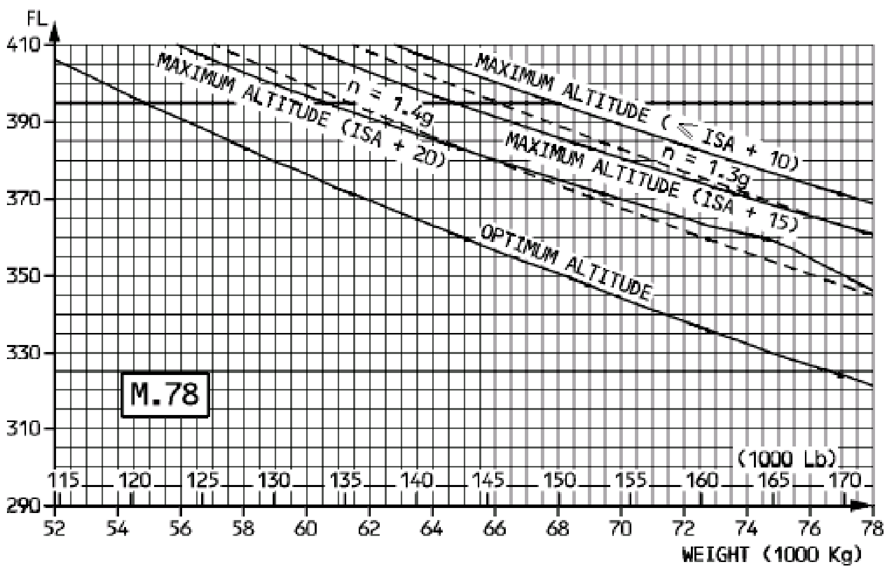
When the aircraft flies at high speed, the polar curve depends on the indicated Mach number, and decreases when Mach increases. So, for each Mach number, there is a different value of $(C_L/C_D)_{max}$, that is lower as the Mach number increases.

When the aircraft is cruising at the optimum altitude for a given Mach, C_L is fixed and corresponds to $(C_L/C_D)_{max}$ of the selected Mach number. As a result, variable elements are weight and outside static pressure (P_s) of the optimum altitude. The formula expressing a cruise at optimum altitude is:

$$\frac{\text{Weight}}{P_s} = \text{constant}$$

In the FCOM Flight Planning Chapters the optimum altitude is shown on the Cruise Level chart for 2 or more speeds. This chart also shows the Maximum Altitudes as limited by performance and buffet. A typical FCOM chart showing the variation of optimum altitude with weight for one speed is shown below.

A318/319/320/321 FLIGHT CREW OPERATING MANUAL	FLIGHT PLANNING	2.05.20	P 2
	CRUISE LEVEL	SEQ 205	REV 26



It should be noted that the influence of airspeed on optimum altitude is not very significant in the range of normal cruise speeds.

In order to minimize fuel burn, the aircraft should therefore be flown at the optimum altitude. However this is not always possible. Performance limitations such as rate of climb or available cruise thrust can lead to a maximum altitude below the optimum, as can buffet limitations. At low weights, the optimum altitude may be above the maximum certificated altitude. In addition, Air Traffic Control restrictions can affect the flown flight level.

The following table shows the specific range penalty of not flying at optimum altitude, assuming a cruise Mach No of 0.8. It should be noted that each airframe/engine combination has different values. It should be noted that these are average values and there are slight variations with different weight/optimum altitude combinations.

Specific Range Penalty for not flying at Optimum Altitude

Aircraft	+2000ft	-2000ft	-4000ft	-6000ft
A300B4-605	2.0%	0.9%	3.4%	9.3%
A310-324	1.9%	1.4%	4.4%	9.3%
A318-111	0.7%	1.6%	5.0%	10.0%
A319-132	1.0%	3.0%	7.2%	12.2%
A320-211	**	1.1%	4.7%	9.5%
A320-232	1.4%	2.1%	6.2%	12.0%
A321-112	2.3%	1.4%	4.6%	15.2%
A330-203	1.8%	1.3%	4.2%	8.4%
A330-343	3.0%	1.0%	3.2%	7.2%
A340-212	1.4%	1.5%	4.0%	8.0%
A340-313E	1.5%	1.6%	5.2%	9.5%
A340-642	1.6%	0.6%	2.2%	5.1%

** Above Maximum Altitude

Generally if one flies within 2000ft of optimum altitude, then the specific range is within about 2% of the maximum. However fuel burn-off is an important consideration.

Consider an A340-313E at a weight such that the optimum altitude is 33000ft. If the aircraft flies at FL 310 the SR penalty is 2.1% for the weight considered. However after a fuel burn of 20800kg, during which the aircraft would have traveled 1400nm the optimum altitude increases to 35000ft and the penalty is now 5.2%.

There is also an effect on block time due to the different altitudes. The true air speed increases/decreases 4kts, or just under 1% for each 2000ft lower/higher cruise altitude.

5.3.2.1 CROSS-OVER ALTITUDE VERSUS OPTIMUM ALTITUDE

It has been previously shown that the TAS is the maximum at the crossover altitude. One can wonder whether it is profitable to stay at this altitude, instead of climbing to the first optimum altitude.

Assuming the standard climb laws, the crossover altitude can be derived. The standard speed laws are tabulated in paragraph 5.2.2.

The next table shows the effect of flying at the crossover altitude instead of optimum flight levels. The 1st optimum flight level has been chosen for the short sectors, whereas longer sectors assume step climbs with FL 310, 350 and 390 being available. This assumes ISA conditions and a take-off weight for a typical sector with max passengers and some freight (2500kg for the A320 family and 5000kg for the other aircraft).

Aircraft type	Sector Distance	Cross-over altitude	Optimum Flight Levels	Gained time (min)	Increase in fuel consumption
A300B4-605R	2000nm	29000 ft	310/350	7	1190kg
A310-324	2000nm	30000ft	350/390	3	2160kg
A318-111	1000nm	29000 ft	370	3	740kg
A319-112	1000nm	29000 ft	370	3	650kg
A320-214	1000nm	29000 ft	350	2	580kg
A320-232	1000nm	29000 ft	340	2	440kg
A321-211	1000nm	29000 ft	330	2	350kg
A330-203	4000nm	31000 ft	350/390	9	5040kg
A330-223	4000nm	31000 ft	350/390	9	5780kg
A330-343	4000nm	31000 ft	350/390	10	6380kg
A340-212	6000nm	29000 ft	310/350/390	17	10900kg
A340-313	6000nm	29000 ft	310/350/390	14	8410kg
A340-313E	6000nm	29000 ft	310/350/390	17	9310kg
A340-500/600	6000nm	29000 ft	310/350/390	18	2430kg

This table shows that flying at crossover altitude increases the fuel burn significantly for a relatively small reduction in block time.

5.3.2.2 CRUISE OPTIMISATION WITH STEPPED CLIMB

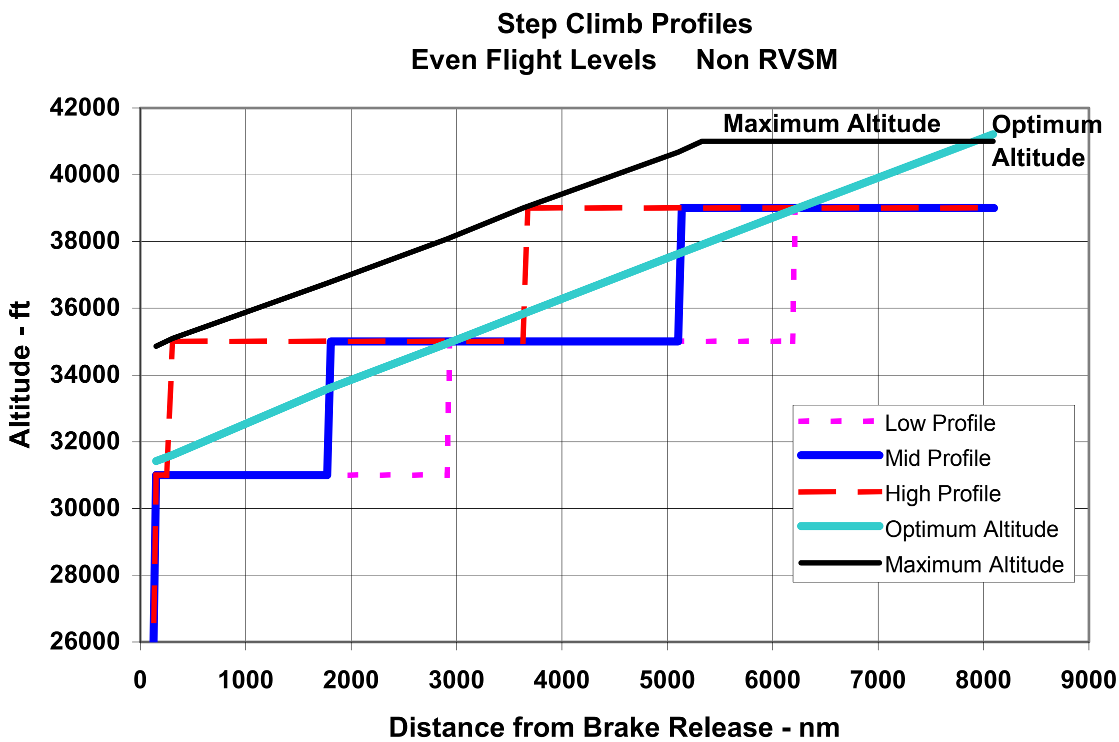
5.3.2.2.1 Introduction

It has been shown that flying at non-optimum altitudes can cause significant fuel penalties, and that the effect of fuel burn is to increase the optimum altitude. The ideal scenario would be to follow the optimum altitude as in the climbing cruise, but A.T.C. constraints, performance and buffet limits do not make this possible. However, by changing the cruise level with step climbs, as the aircraft gets lighter the aircraft will remain as close as possible to the optimum altitude.

5.3.2.2.2 Choice of Profile

Several parameters such as weather conditions, ATC requirements, may influence any decision made by the crew with regard to three fundamental priorities: maneuverability, passenger comfort, and economics.

This pertains to the choice of the cruise flight level that can be made according to the three following climb profiles as shown below for an A340-642:



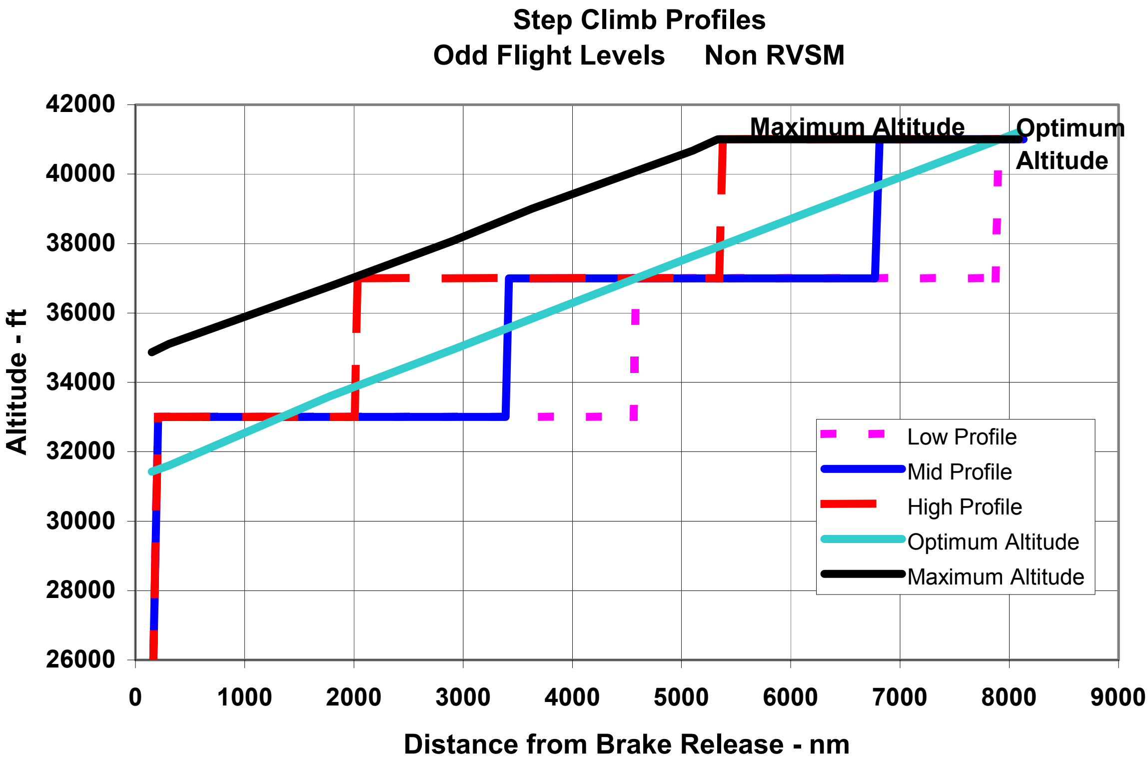
The **Low profile** initiates the step climb at the weight where the next available flight level is also the optimum flight level at that weight. Consequently the flight levels are always at or below the optimum. This has the advantage of better maneuverability margins and generally a better speed as it is closer to the crossover altitude.

The **high profile** initiates the step climb at the weight where the next available flight level is also the maximum flight level at that weight. The flight levels are mainly above the optimum and the aircraft will have decreased maneuverability and fly slower.

The **mid profile** initiates the step climb at the weight where the specific range at the next available flight level is better than that at the current flight level. This enables the flight profile to remain as close as practically possible to the optimum flight level. It is this technique that is recommended for best fuel economy, and is also very close to that required for best economics.

It is interesting to note that, in this case, the Mid profile step climb is made 1140nm before the Low Profile step climb and 1520nm after the High profile step climb.

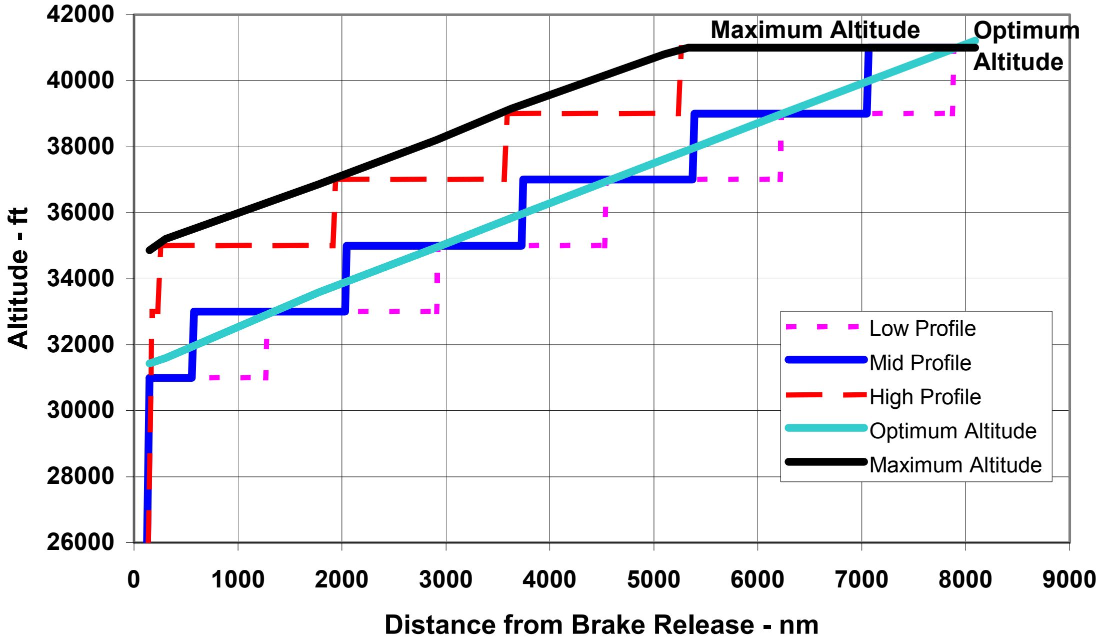
The situation changes with odd flight levels:



Because of the different available flight levels, the step climbs are initiated some 1500nm further than the even flight level step climb points. However the relative merits of each profile remains the same.

With Reduced Vertical Separation Minima (RVSM) the difference between flight levels reduces from 4000 to 2000ft and this enables the aircraft profile to remain much closer to the optimum. In addition the high profile (depending on the aircraft) remains much higher than the optimum, increasing the fuel penalty. This profile is shown on the following page.

Step Climb Profiles
Odd Flight Levels RVSM



Thus pilots are advised to perform step climbs around the optimum altitudes. To facilitate this, the optimum weight for climb to the next flight level is given in most FCOM's (not A300/A310). An example is shown below.

A318/319/320/321 FLIGHT CREW OPERATING MANUAL	FLIGHT PLANNING	2.05.20	P 1
	CRUISE LEVEL	SEQ 205	REV 31

R **OPTIMUM WEIGHT FOR 4000 FEET STEP CLIMB**

R

STEP CLIMB FROM/TO	WEIGHT (1000 kg/1000 lb)					
	≤ ISA + 10		ISA + 15		ISA + 20	
	LR	M.78	LR	M.78	LR	M.78
310/350	74/163	75/165	74/163	75/165	74/163	75/165
330/370	68/149	68/149	68/149	68/149	67/147	68/149
350/390	61/134	62/136	61/134	62/136	61/134	62/136
370/410	55/121	56/123	55/121	56/123	55/121	56/123

On all Airbus FMS-equipped aircraft, the optimum altitude (OPT FL) and the maximum flight level (MAX FL) are displayed on the MCDU progress page. The recommended maximum altitude in the FMGC ensures a 0.3g buffet margin, a minimum rate of climb of 300ft/min at MAX CLIMB thrust and a level flight at MAX CRUISE thrust. Depending on weight and type, it is 2000 to 4000ft above the optimum altitude.

Typical cruise distances between 2000 foot altitude steps are shown in the following table:

Type	Distance - nm
A300	1000 - 1100
A310	1150 - 1250
A320	1200 - 1300
A330	1500 - 1650
A340	1500 - 1650
A340-500/600	1600 - 1700

For sector lengths greater than these, where ATC restrictions do not allow a change in cruise altitude from the initial requested level, the initial request should be the highest compatible with the maximum cruise altitude.

5.3.2.3 DELAYS IN ALTITUDE CHANGES

Let's consider an aircraft that is at flight level 330, which has, at that weight, an optimum flight level of 370. If it does not climb to FL 370 for ATC or other reasons, it will consume more fuel. The following table shows the difference in fuel burn for a 500nm still air cruise, when cruising at FL 330 instead of FL 370.

Aircraft Type	Fuel Increase (kg)	Fuel Increase (%)
A300B4-605R	238	5.2
A310-324	221	5.3
A318-111	150	6.2
A319-132	184	7.9
A320-211	158	6.2
A320-232	187	7.9
A321-112	155	5.5
A330-203	324	5.5
A330-343	342	5.6
A340-212	393	6.2
A340-313E	378	6.0
A340-500/600	336	4.1

Thus delaying a climb to a higher altitude has a significant impact on fuel burn.

5.3.2.4 OPTIMUM ALTITUDES ON SHORT STAGES

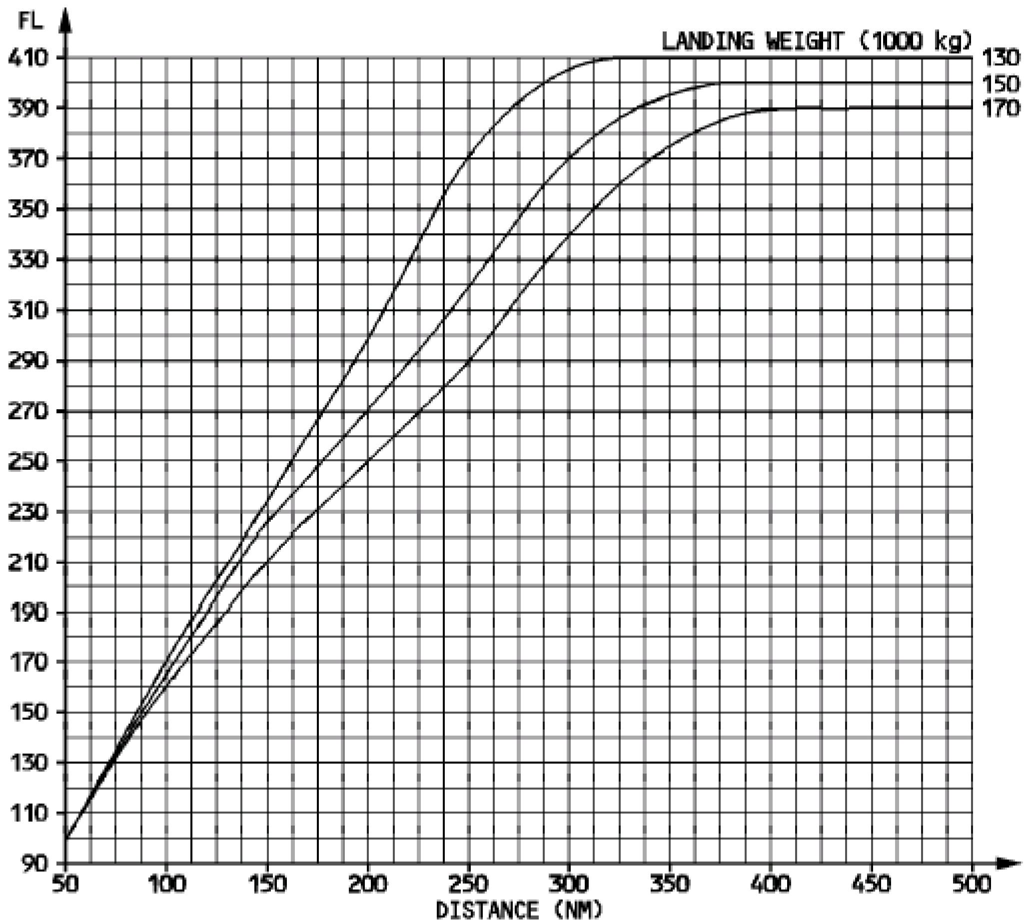
For short stages, the choice of cruise flight level is often restricted due to the necessary climb and descent distance. Airbus philosophy assumes a minimum 5 minute cruise sector, because a climb followed immediately by the descent is not appreciated by pilots, passengers or ATC.

If the stage length is of sufficient length that the optimum flight level can be reached, but the cruise is of short duration, then the benefits at this flight level will be marginal. It may even be worthwhile to cruise at one flight level lower, as the increased climb consumption offsets any reduced cruise consumption.

In the FCOM there is a chart showing the optimum altitude on a short stage. An example is shown below.

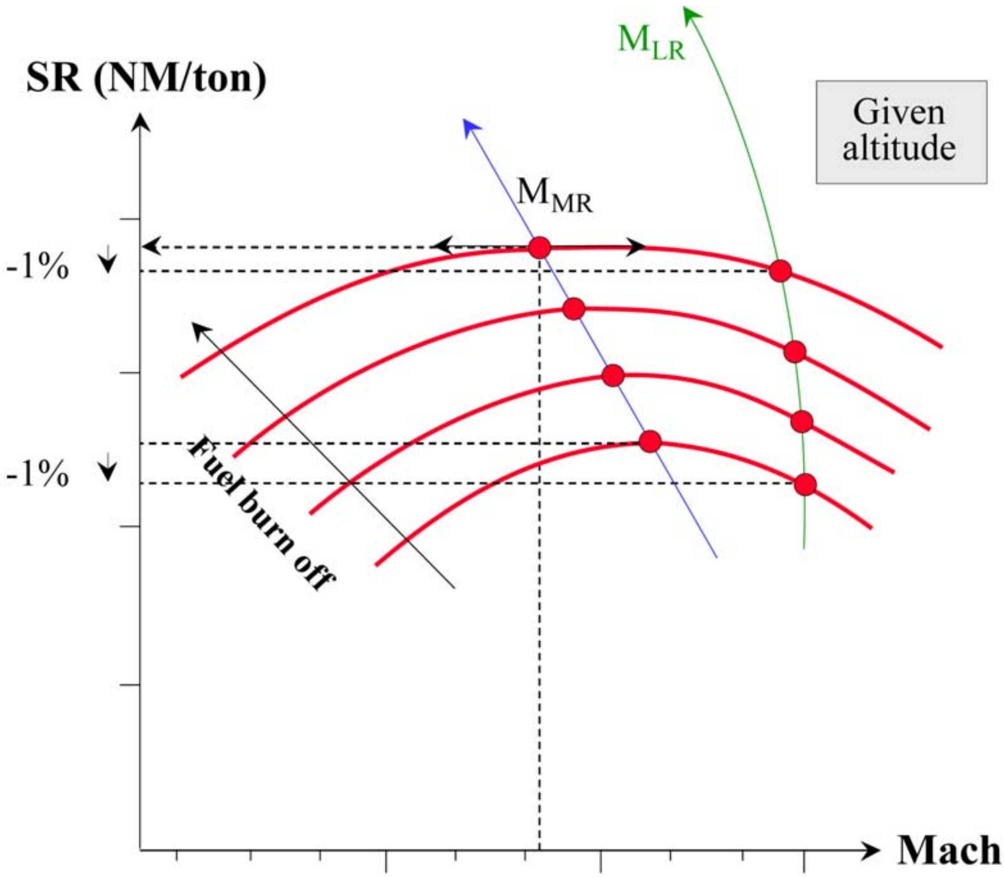
A330 FLIGHT CREW OPERATING MANUAL	FLIGHT PLANNING	2.05.20	P 4
	CRUISE LEVEL	SEQ 070	REV 06

OPTIMUM ALTITUDE ON SHORT STAGE



5.3.3 CRUISE SPEED OPTIMISATION

Having been given a flight level which may be a requested optimum altitude or one imposed by air traffic control, speed is the only remaining parameter that requires selection. The following picture shows the variation of Specific Range with Mach Number for different aircraft weights at a fixed altitude.

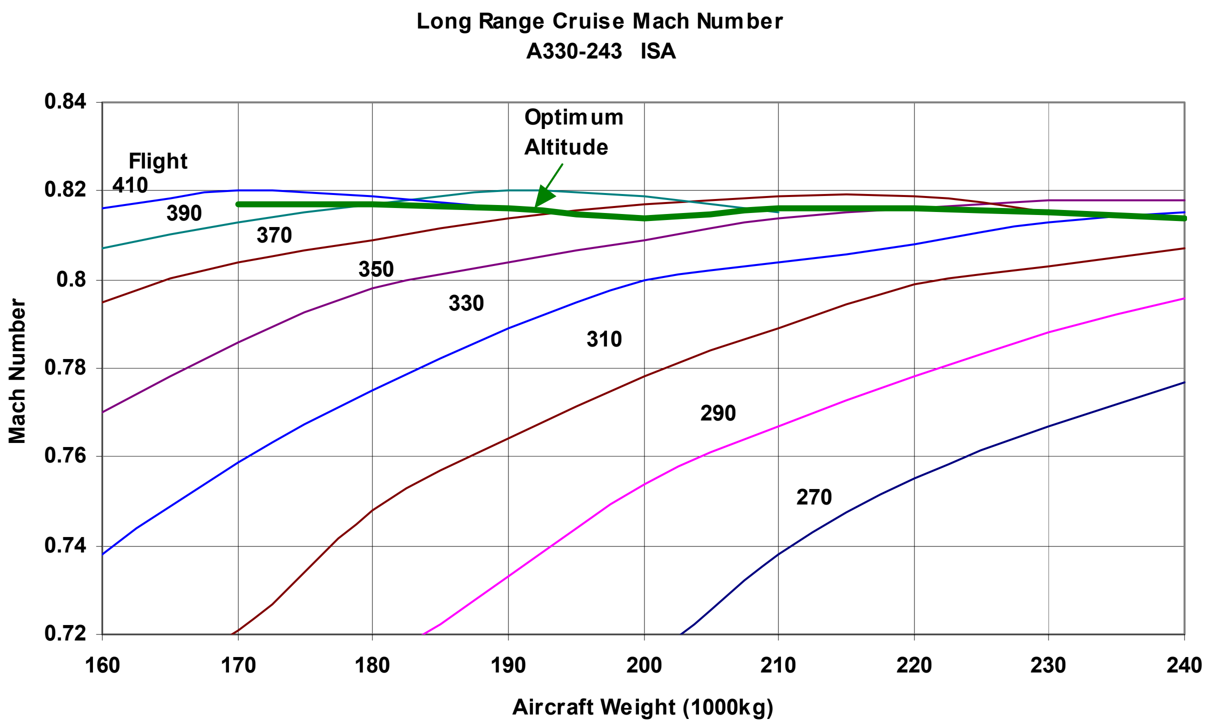


The Mach number, which gives the best specific range, can be determined. It is called the maximum range cruise Mach (M_{MR}). Nevertheless, for practical operations, a long-range cruise procedure is defined which gains a significant increase in speed compared to M_{MR} with only a 1% loss in specific range. Like the M_{MR} speed, the M_{LRC} speed also decreases with decreasing weight, at constant altitude.

A more detailed explanation of this can be found in "Getting to Grips with Aircraft Performance"

The following chart shows the typical variation of the Long Range Cruise Mach Number with aircraft weight for various flight levels. Also plotted on this chart is the optimum altitude line. This shows that there is not much variation in the long-range cruise mach number at these altitudes.

It would therefore be possible to fly a constant Mach number procedure instead of the variable LRC speed procedure. In order to save fuel however, the exact LRC speed should be maintained.

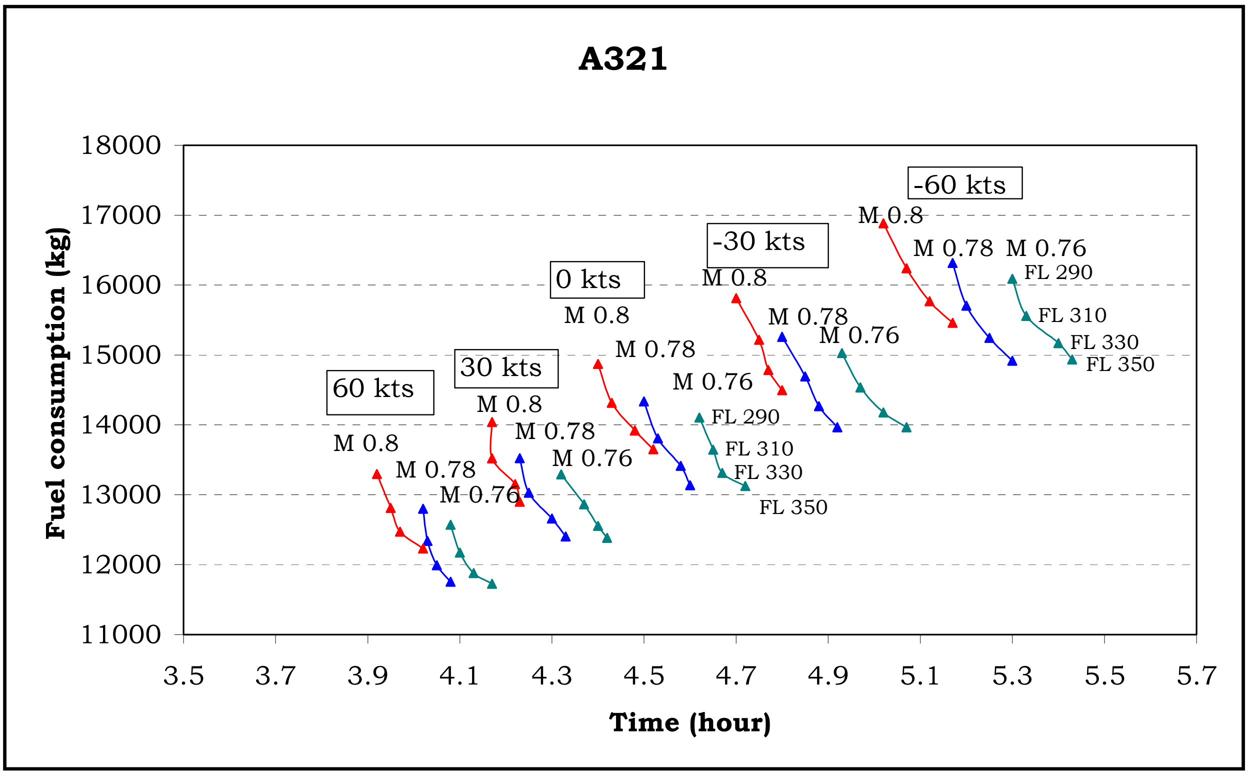


The Long Range Cruise Speed can be found in the Cruise tables in the FCOM.

5.3.4 WIND INFLUENCE

Wind can have a significant influence on fuel burns. Nowadays, meteorological forecasts are very reliable and its integration into the FMS provides accurate information to crews. Hence the latter best perform flight planning with a view towards fuel savings.

The effect of the wind on trip time and fuel is shown on the following chart, which gives fuel consumption and time for a 2000nm sector, with respect to flight levels, Mach number and wind (tailwind positive) for a fixed take-off weight.

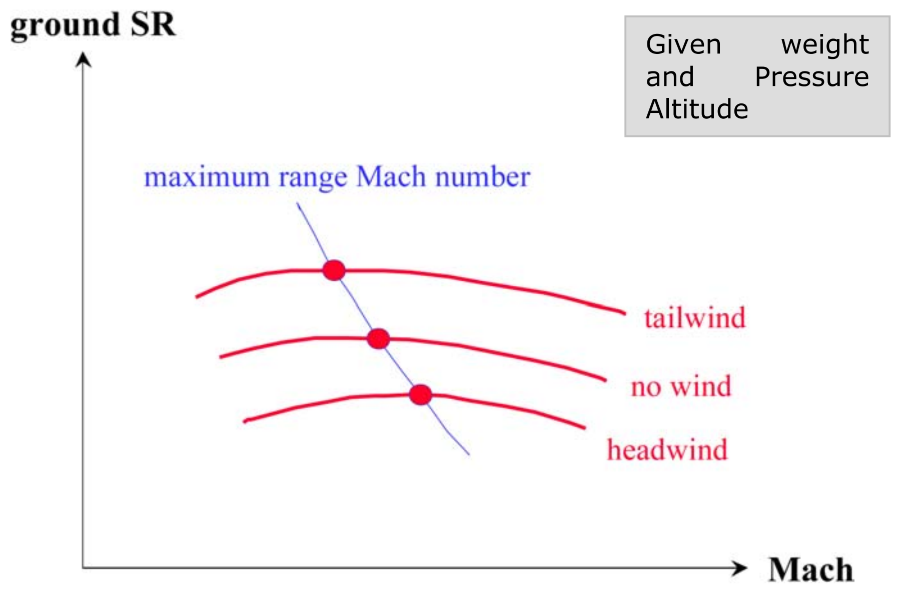


This plot graphically shows the magnitude of the significant changes in fuel consumption and time due to winds. FCOM Tables show the equivalent still air distances for any ground distance/wind combination.

However the winds can affect the performance optimization as well as changing the effective still air distance. The M_{MR} (or M_{LRC}) value varies with headwind or tailwind, due to changes in the SR.

The effect of a tailwind is to increase the ground speed, and therefore the SR, by the ratio of ground speed to airspeed. A given wind speed therefore has a larger effect at the lower airspeeds, which changes the optimum speed.

The following chart shows the Maximum Range Mach number versus wind variations.



M_{MR} and wind influence

This shows that

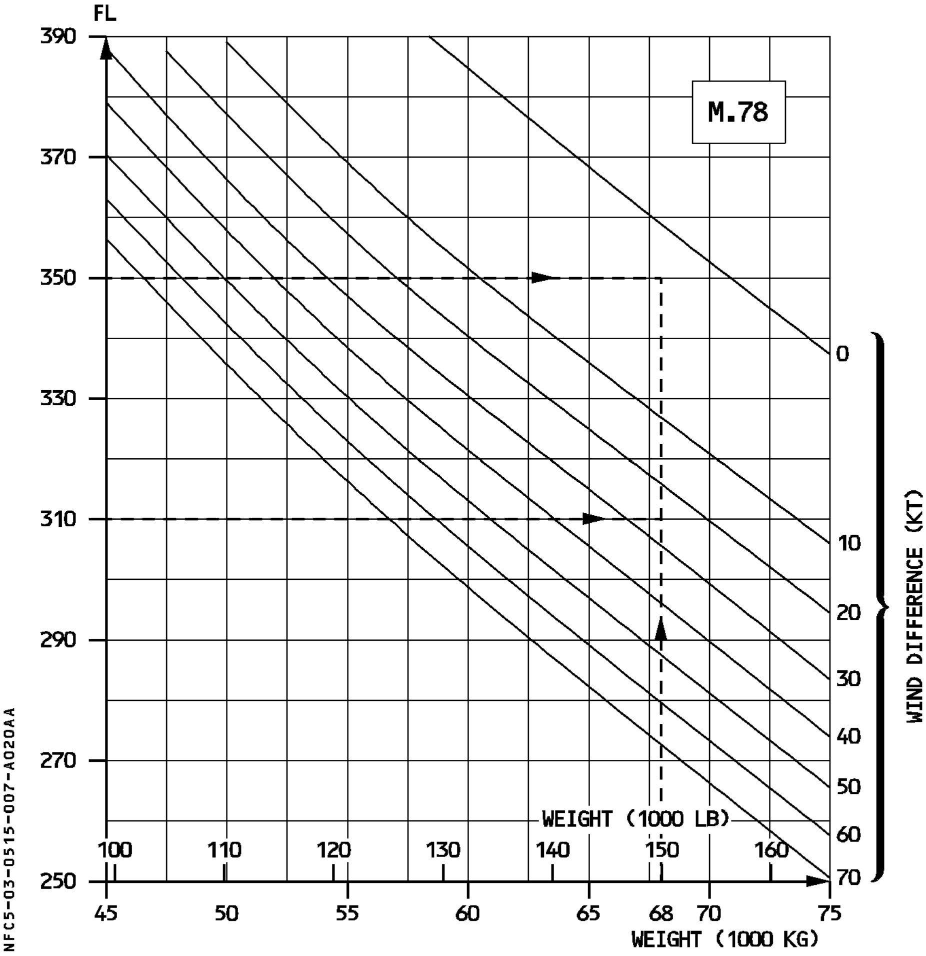
Tailwinds increase the specific range and lower the speeds Headwinds decrease the specific range and raise the speeds.

The wind speed can be different at different altitudes. For a given weight, when cruise altitude is lower than optimum altitude, the specific range decreases. Nevertheless, it is possible that, at a lower altitude with a favorable wind, the ground specific range improves. When the favorable wind difference between the optimum altitude and a lower one reaches a certain value, the ground-specific range at lower altitude is higher than the ground-specific range at optimum altitude. As a result, in such conditions, it is more economical to cruise at the lower altitude.

There is information in the most FCOM's (not A300/310) to indicate the amount of favorable wind, necessary to obtain the same ground-specific range at altitudes different from the optimum. If the wind is more favorable then it is beneficial to fly lower. The following shows such a page:

A319/320/321 FLIGHT CREW OPERATING MANUAL	IN FLIGHT PERFORMANCE CRUISE	3.05.15 P 7 SEQ 020 REV 24

WIND ALTITUDE TRADE FOR CONSTANT SPECIFIC RANGE



GIVEN : Weight : 68000 kg (150 000 lb)
Wind at FL350 : 10 kt head

FIND : Minimum wind difference to descend to FL310 : (26 – 3) = 23 kt

RESULTS : Descent to FL310 may be considered provided the tail wind at this altitude is more than (23 – 10) = 13 kt.

5.3.5 MANAGED MODE

The flight management system (FMS) optimizes the flight plan for winds, operating costs and suggests the most economical cruise altitude and airspeed, depending on the cost index chosen by the airline. An airline that wants to save fuel has to choose a low cost index. The next part intends to highlight the impact of the cost index on fuel consumption and on trip time. More complete information can be found in the "Getting to Grips with Cost Index" brochure.

5.3.5.1 ECONOMIC MACH NUMBER

Long-range Cruise Mach number was considered as a minimum fuel regime. If we consider the Direct Operating Cost instead, the **Economic Mach number** (**M_{ECON}**), can be introduced.

Direct Operating Costs (DOC) are made up of fixed, flight-time related and fuel-consumption related costs. As a result, for a given trip, DOC can be expressed as:

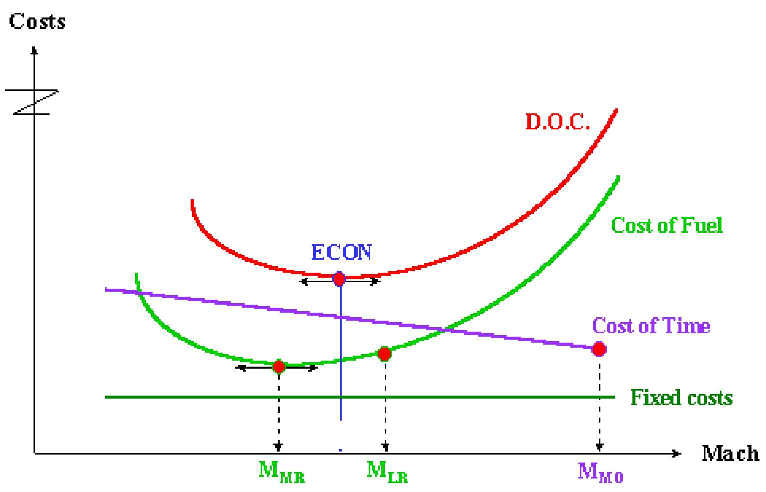
$$DOC = C_C + C_F.\Delta F + C_T.\Delta T$$

where C_C = fixed costs

C_F = cost of fuel unit ΔF = trip fuel

C_T = time related costs per flight hour ΔT = trip time

As DOCs are calculated per nautical mile, it is possible to plot fuel-related costs, flight-time related costs, and direct operating costs based on Mach number .



Minimum fuel costs correspond to the Maximum Range Mach number. The minimum DOC corresponds to a specific Mach number, referred to as Econ Mach (M_{ECON}).

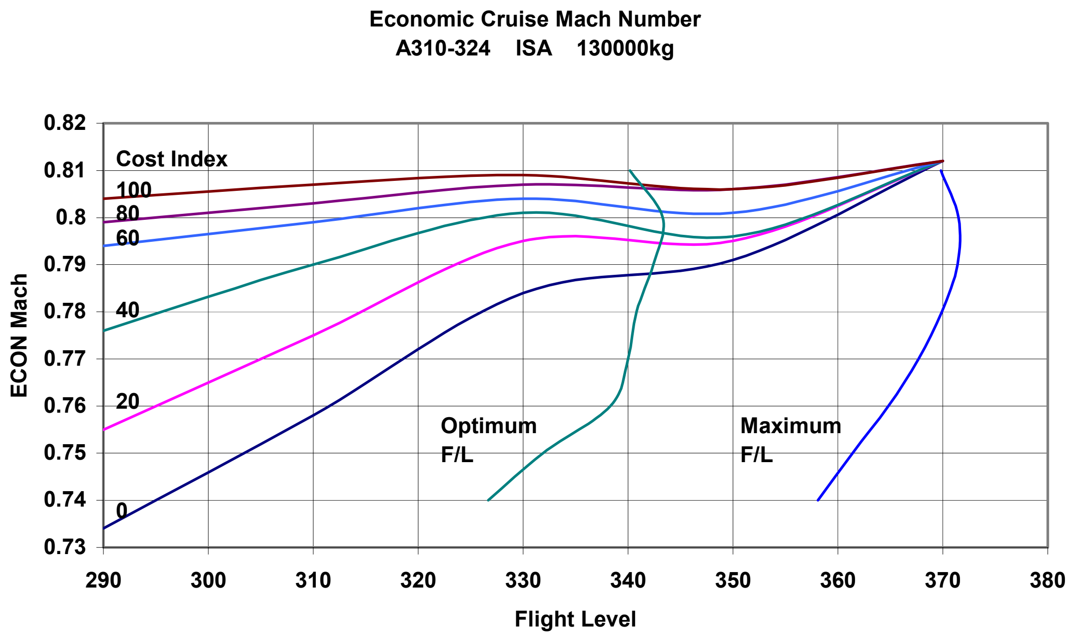
$FL = \text{constant}$	weight	↘	$\Rightarrow M_{ECON}$	↘
$\text{weight} = \text{constant}$	FL	↗	$\Rightarrow M_{ECON}$	↗

The M_{ECON} value depends on the time and fuel cost ratio. This ratio is called **cost index** (**CI**), and is usually expressed in kg/min or 100lb/h:

$$\text{Cost Index (CI)} = \frac{\text{Cost of time}}{\text{Cost of fuel}} = \frac{C_T}{C_F}$$

Depending on the cost index, the predicted aircraft and atmospheric conditions, the optimum altitude and the economic Mach number are computed. From then on, fuel consumption depends only of the chosen cost index.

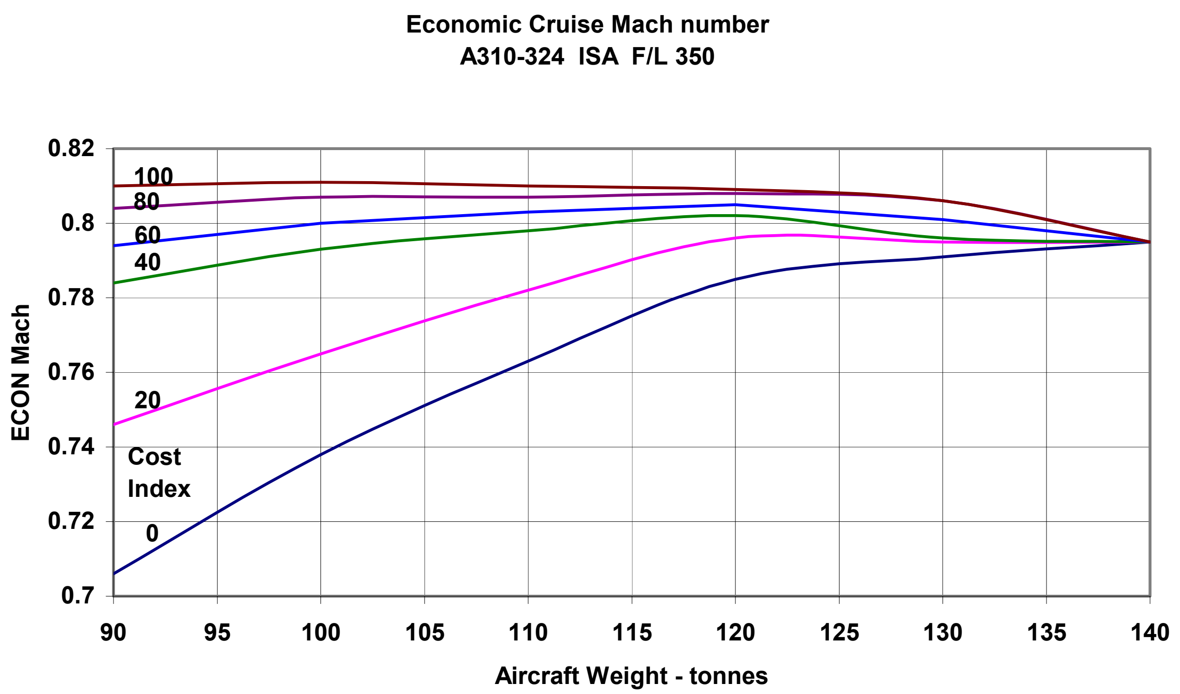
The following chart shows the economic Mach number variation with flight level for different cost indices.



This shows the general trend, common with all aircraft, of increasing economic Mach number with flight level.

The charts also show large economic Mach number changes with flight level for low cost indices, whereas it is rather constant for high cost indices. The economic Mach is very sensitive to the cost index when flying below the optimum altitude.

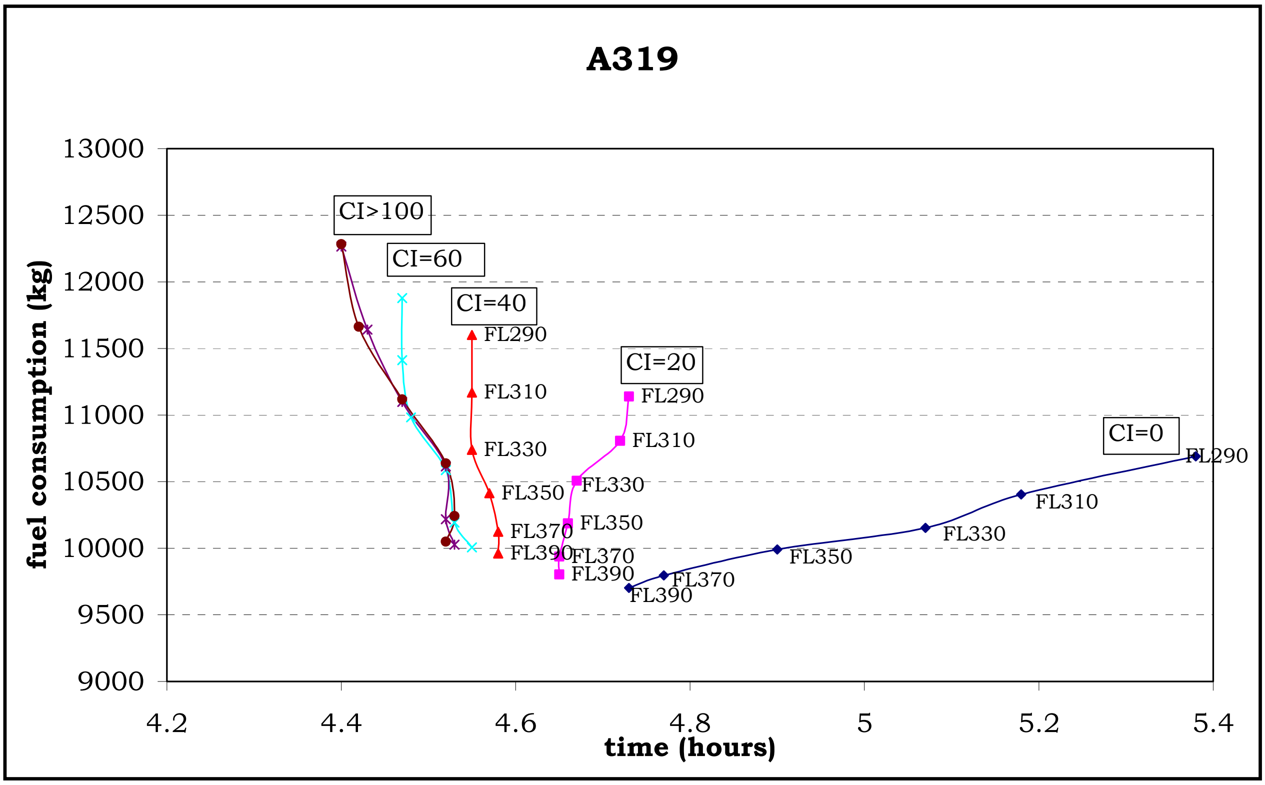
The effect of weight variation at a fixed flight level is shown below.



The charts show that for high cost indices, the economic Mach number stays fairly constant throughout the flight. Nevertheless, for a low cost index, the economic Mach number reduces significantly as the weight reduces. This is quite normal as low cost indices favor fuel consumption at the expense of time. Moreover, we notice that for low cost indices, a small cost index increment has a far-reaching influence on the economic Mach number, and hence on flight time. These trends are typical of all aircraft.

5.3.5.2 TIME/FUEL RELATIONSHIP

To know whether the fuel economies at low cost indices are worthwhile, the impact of cost index on time has to be considered. The following graph show both trip fuel and time for different flight levels and cost indices. The shape of this chart is typical of all types.



As it can be seen, it is not really advantageous to fly at very low cost indices as fuel savings are not significant compared to time loss. Although using slightly higher fuel, a slightly higher cost index gives significant time gains.

For instance, for the A319, increasing the cost index from 0 to 20 reduces the block time by 15 minutes (5%) for a fuel burn increase of only 200kg (2%) on a 2000nm sector.

5.3.6 EFFECT OF SPEED INCREASE ON MANAGED MODE

Flying at a given cost index rather than at a given Mach number provides the added advantage of always benefiting from the optimum Mach number as a function of aircraft gross weight, flight level and head/tailwind components.

This means the ECON mode ("managed" mode) can save fuel relative to fixed Mach schedules ("selected" mode) and for an equivalent time.

One can wonder whether selecting a higher Mach number than the one chosen by the FMS has a significant impact on fuel consumption. Imagine an aircraft flying at flight level 370, in managed mode and at the optimum weight of FL370. The FMS computes the optimum speed based on cost index, temperature and wind. If the pilot selects another (higher) Mach number, the fuel consumption will increase.

The following tables show the effect of such a speed increase.

		Economic Mach No + 0.005			Economic Mach No + 0.01		
		Fuel Penalty		∆Time	Fuel Penalty		∆Time
Aircraft	Sector	Kg	%	Min	Kg	%	Min
A300-605	2000 Nm	110	0.4	1	230	0.9	3
A310-324	2000 Nm	90	0.4	1	430	2.0	8
A318	1000 Nm	30	0.5	1	60	1.0	1
A319	1000 Nm	20	0.2	1	40	0.6	2
A320	1000 Nm	20	0.3	1	40	0.7	2
A321	1000 Nm	10	0.1	1	30	0.4	1
A330	4000 Nm	150	0.3	3	330	0.6	6
A340-212	6000 Nm	390	0.5	5	790	0.9	10
A340-313E	6000 Nm	380	0.4	5	900	1.0	10
A340-500	6000 Nm	1050	0.9	5	2540	2.1	9
A340-600	6000 Nm	820	0.7	4	2060	1.8	9

We notice that although decreasing block times, the increase of Mach number above the Optimum speed can result in significant increases in fuel burn. Pilots hence have to be patient and should not change the Mach number even when under the impression that the aircraft does not fly fast enough.

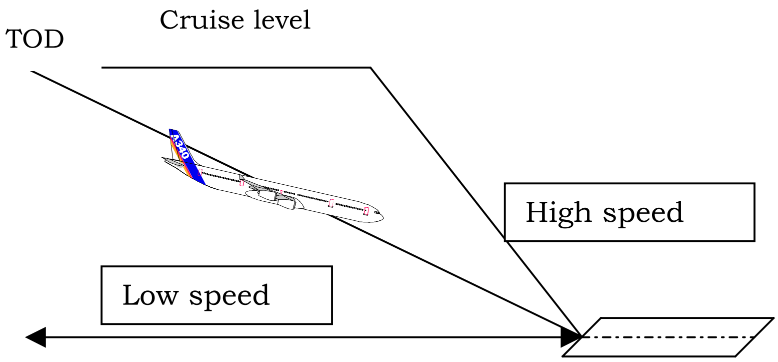
Moreover, when possible, the managed mode must be kept.

5.4 DESCENT

5.4.1 INTRODUCTION

Depending on the descent law, flight paths do vary in steepness.

Indeed, the higher the speed law, the steeper the flight path.



Descent profiles.

Descents are normally performed in three phases on a constant IAS/Mach descent speed schedule, as follows:

- Constant Mach number is maintained until the crossover altitude
- Constant indicated air speed is maintained down to 10000ft
- 250 KT indicated air speed (IAS) is maintained below flight level 100, until the aircraft decelerates for landing

The engine thrust is normally set to flight idle for the descent and the speed is controlled by the aircraft attitude. In these conditions higher weights increase the descent distance because of the reduction of descent gradient (which equals [thrust-drag]/weight in stabilized flight). This also increases the descent fuel.

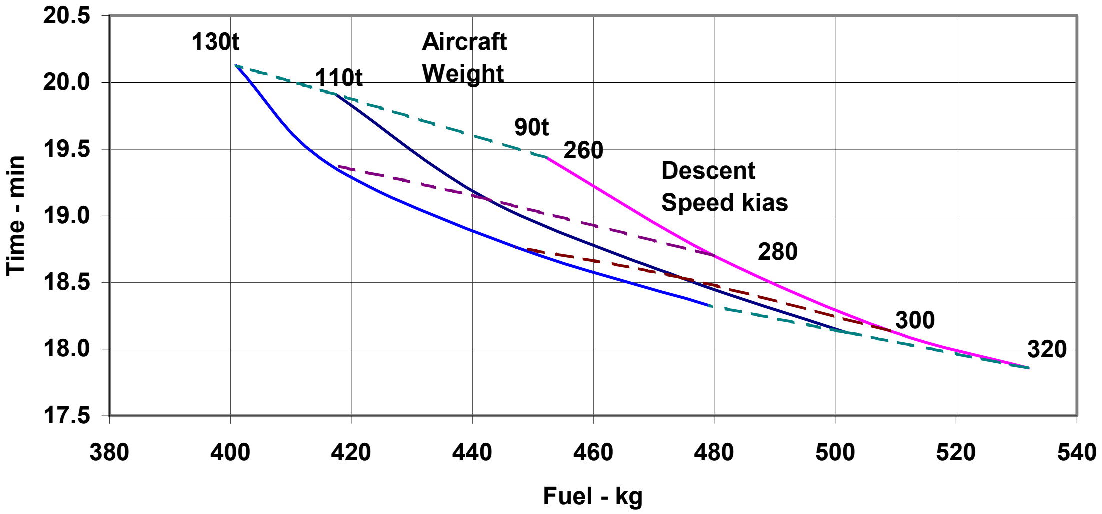
However a descent from high altitudes at low weight may lead to a gradient of descent that results in an excessive cabin rate of descent. In these cases the rate of descent is reduced by application of power, until a flight idle descent can be continued. This results in what is known as the re- pressurization segment, and this can reverse the weight-descent distance relationship.

To correctly evaluate the effects of descent techniques, cruise and descent flight must be viewed in relation to each other. A short descent distance for example extends the cruise distance. One has therefore to consider in addition to the descent, a small portion of the cruise to the same distance.

5.4.2 THE EFFECT OF DESCENT TECHNIQUES ON FUEL BURN

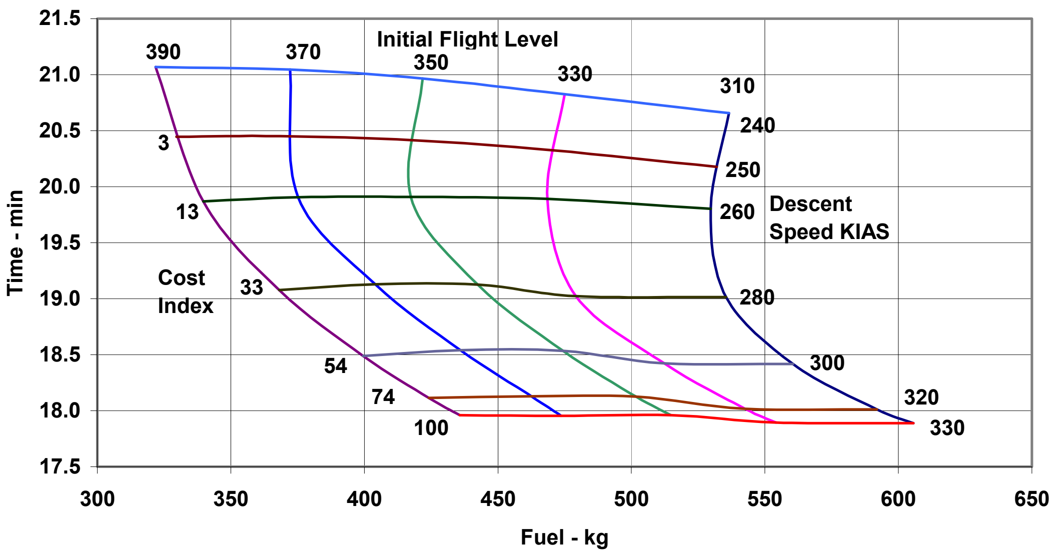
An evaluation has been made of the fuel burn to a constant distance, and this now shows that the higher weights use less fuel. Lower speeds, although requiring more fuel for the descent only requires less total fuel because of the longer descent distance. This is shown in the following chart.

Effect of Descent technique on Fuel and Time for 115nm
A310-324 ISA F/L 350



At a fixed weight, the following chart shows that the minimum fuel occurs at a descent speed of 240kias to 280kias, dependant on flight level.

Effect of Descent Technique on Fuel and Climb for 115nm
A310-324 ISA 110000Kg



However there is a significant time penalty at these speeds.

Note that the effect of the descent Mach number is very dependant on cruise flight level and descent speed, but is relatively small compared to the descent speed effect, and is not fully investigated here.

These descent charts are typical of the other Airbus aircraft. Generally they show a minimum fuel speed of 260 to 280 kts for flight level 310, reducing to 240kts for flight level 390. The exceptions are the A318, A319, A320 and A330, which show the minimum fuel at 240kias for all flight levels which is slightly lower than the other aircraft at FL310.

Appendix B presents some examples of these descent charts for other Airbus aircraft.

The following tables show, for various Airbus aircraft, the descent time and fuel variations for a fixed distance, from FL 350, relative to a 300kias reference speed.

Type	∆Fuel – kg					
	240KT	260 KT	280 KT	300 KT	320 KT	330/340KT *
A300	-55	-60	-30	0	25	35
A310	-55	-60	-30	0	25	40
A318, 319, 320	-50	-40	-20	0	20	25
A321	-35	-40	-20	0	20	35
A330	-110	-105	-60	0	50	70
A340–200/300	-70	-90	-50	0	50	75
A340-500/600	-125	-130	-70	0	70	100

Type	∆Time – minutes					
	240 KT	260 KT	280 KT	300 KT	320 KT	330/340KT *
A300	2.7	1.5	0.6	0	-0.4	-0.6
A310	2.4	1.4	0.6	0	-0.4	-0.6
A320 family	2.6	1.4	0.6	0	-0.4	-0.6
A330	3.5	2.0	0.8	0	-0.6	-0.8
A340–200/300	3.2	1.8	0.8	0	-0.6	-0.8
A340-500/600	3.3	1.9	0.8	0	-0.6	-0.8

* A300/A310/A320 330kias A330/A340 340kias

Comparing these tables to the equivalent climb comparison tables in chapter 5.2.4, it can be noticed that descent techniques often have a greater effect on fuel and time than climb techniques.

5.4.3 MANAGED MODE DESCENT

The FMS computes the Top Of Descent (TOD) as a function of the cost index. We notice that the higher the cost index:

The steeper the descent path (the higher the speed)

The shorter the descent distance

The later the top of descent.

Descent performance is a function of the cost index; the higher the cost index, the higher the descent speed. But contrary to climb, the aircraft gross weight and the top of descent flight level appear to have a negligible effect on the descent speed computation.

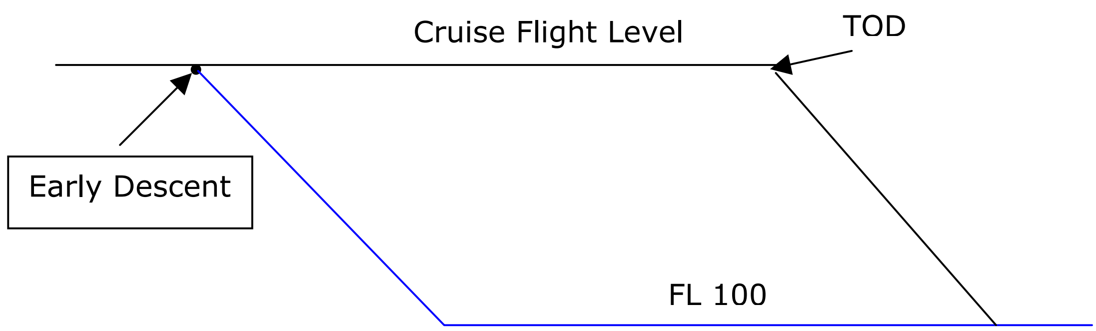
It can be noticed that time to descent is more dependant on cost indices than the time to climb.

On the Effect of Descent Technique on Fuel and Time chart, the cost index has been annotated for each speed. It can be seen that the minimum fuel is at a CI of 0, and the minimum time occurs with a high CI, as would be expected.

For the A300, A310 and A320 family the speed at zero cost index is about 250kias. For the A330/340 it is about 270kias. Max speed normally corresponds with a high cost index of 60 to 120. Once more it can be seen how, in the managed mode, the cost index is used to choose the balance between fuel burn and flight time.

5.4.4 EARLY DESCENT

If the aircraft begins its descent too early, the aircraft would leave its optimal flight level, where fuel consumption is at its best, and would have to cruise at a lower altitude to arrive at the same point.



Two descent situations were simulated:

• Descent commenced 15nm (or about 2 minutes) early followed by a level-off at FL100.

• Cruise continued from the early descent point until the optimum start of descent, followed by the descent

At 10000ft, the cruise speed could be selected between LRC and max speed. If in managed mode, one could continue at the same cost index, or select the 250kias below 10000ft limiting speed. The following table compares the two options.

Aircraft	250KIAS at FL100		LRC at FL100	
	∆Fuel – kg	∆Time – min	∆Fuel – kg	∆Time – min
A300-600	70	1.1	95	0.4
A310	70	1.1	90	0.3
A320 family	50	1.1	65	0.2
A330	80	1.2	100	0.5
A340-200/300	95	1.2	105	0.5
A340-500/600	135	1.2	125	0.5

Cruising faster at 10000ft reduces the time penalty at the expense of fuel.

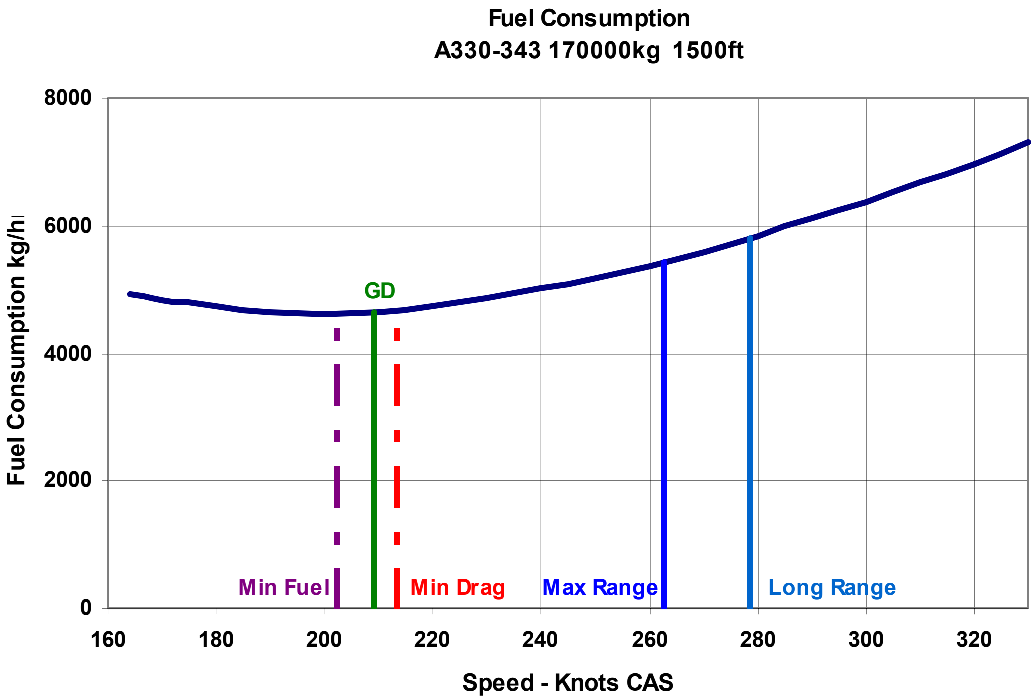
After a long flight with an A340–500 or –600, starting the descent some 100nm early would not appear to be significant in the overall flight. However this can result in a 900kg fuel burn increase and 8 minutes longer block time.

5.5 HOLDING

5.5.1 INTRODUCTION

When holding is required, it is generally flown on a "race track pattern", composed of two straight legs plus two 180 degree turns. In a hold the distance covered is not the primary objective. On the contrary, the knowledge of the maximum holding time (maximum endurance) is a determining factor for any diversion decision. As a result, it is important, during holding, to try to minimize fuel by simply minimizing fuel flow.

For all aircraft, the minimum fuel consumption speed is very close to the maximum lift-to-drag ratio (Green Dot) speed as shown below. As a result, in clean configuration, the standard holding speed is selected equal to **green dot** speed (GD).



Holding patterns may be quite limiting around certain airports due to obstacle proximity. Therefore, green dot is sometimes too high, especially during turn phases where the bank angle can be too significant. As it is not possible to significantly reduce the speed below green dot in clean configuration, slats may be extended and a holding done in **CONF1** at "**S**" speed. (min slat retraction speed Conf 1 to Conf clean).

At other airports, Air Traffic Control may require the hold to be performed at a certain speed, and it may not be possible fully optimise the fuel burn. In order to allow flexibility in planning and operations, the FCOM has four different holding speed and configuration combinations, adapted to each type of aircraft.

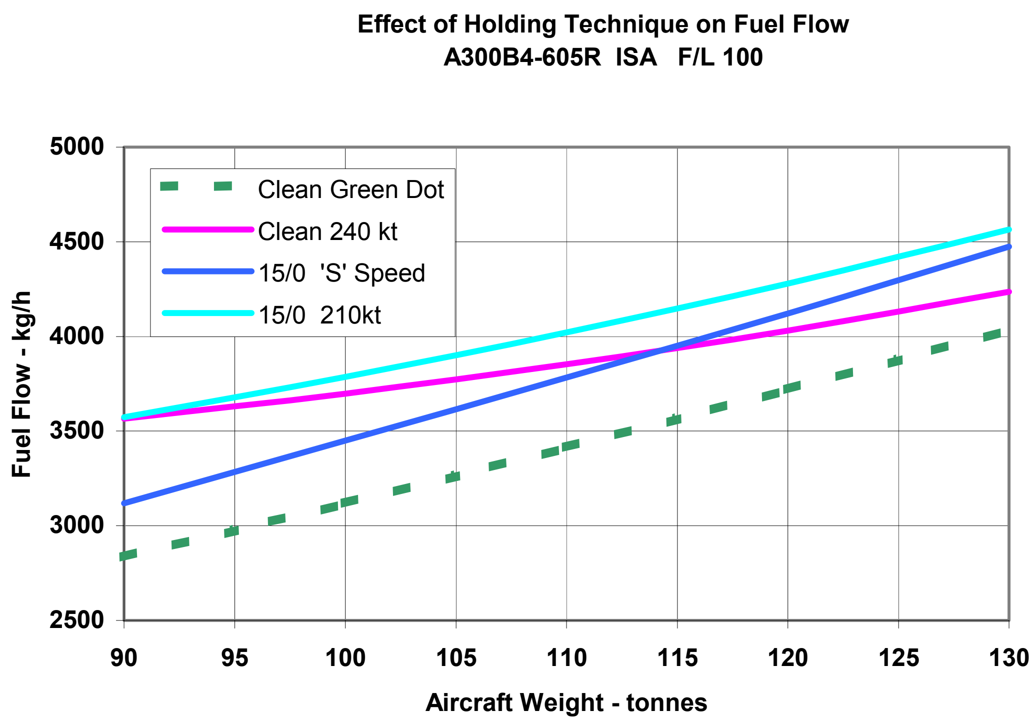
The following table gives the configurations and speeds for each type.

Aircraft types	First Flap/slat Configuration		Clean configuration	
A300-600	210kts	S speed	240kts	Green Dot
A310	170kts	S speed	210kts	Green Dot
A320 Family (CFM)	170kts	S speed	210kts	Green Dot
A320 Family (IAE)	170kts	S speed	210kts	Green Dot + 20
A330	170kts	S speed	210kts	Green Dot
A340-200/300	210kts	S speed	240kts	Green Dot
A340-500/600	240kts	S speed	-	Green Dot

For the A300/A310 the first configuration is flap 15, slat 0. For the other aircraft this is Conf 1. Note that the fourth combination for the A340-500/600 is Configuration 2 at 210kts.

5.5.2 VARIOUS CONFIGURATION / SPEED COMBINATIONS

The following graphs show the holding fuel flow variation with weight for the four different holding configurations. This is done at an altitude of 10000ft.



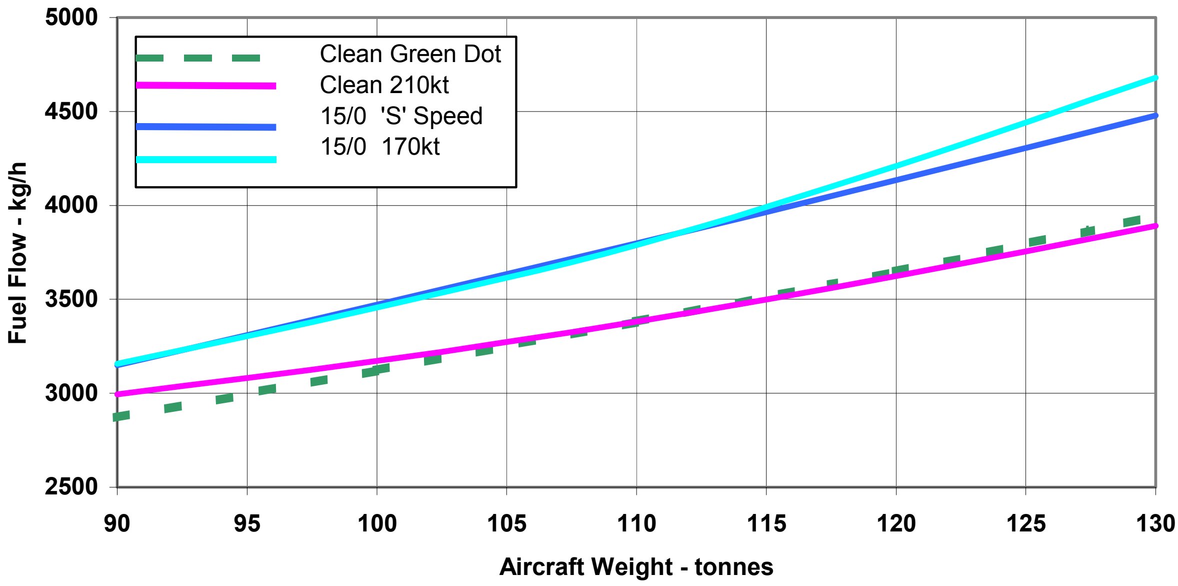
This graph is for an **A300** and it shows the advantage of holding in a clean configuration at the green dot speed. The clean configuration fixed speed of 240kt is significantly higher than the green dot speed; hence the large increase in fuel flow with this technique. The 15/0 configuration with a fixed speed of 210kt is also significantly higher than the 'S' speed, hence higher fuel flows.

The large variation in fuel flow shows how important it is to use the right configuration and speed, compatible with the other operational requirements.

The **A340-200/300** schedules the same hold speeds as the A300, and the graphs have a similar form with a large increase in fuel flow at low weights with the fixed speed techniques. However at high weights the difference is much smaller. There is also a large increase when using Conf 1. Once more holding clean at green dot speed gives the lowest fuel flow.

The following graph is for the **A310** and this shows completely different characteristics because of the lower fixed speeds used in each configuration.

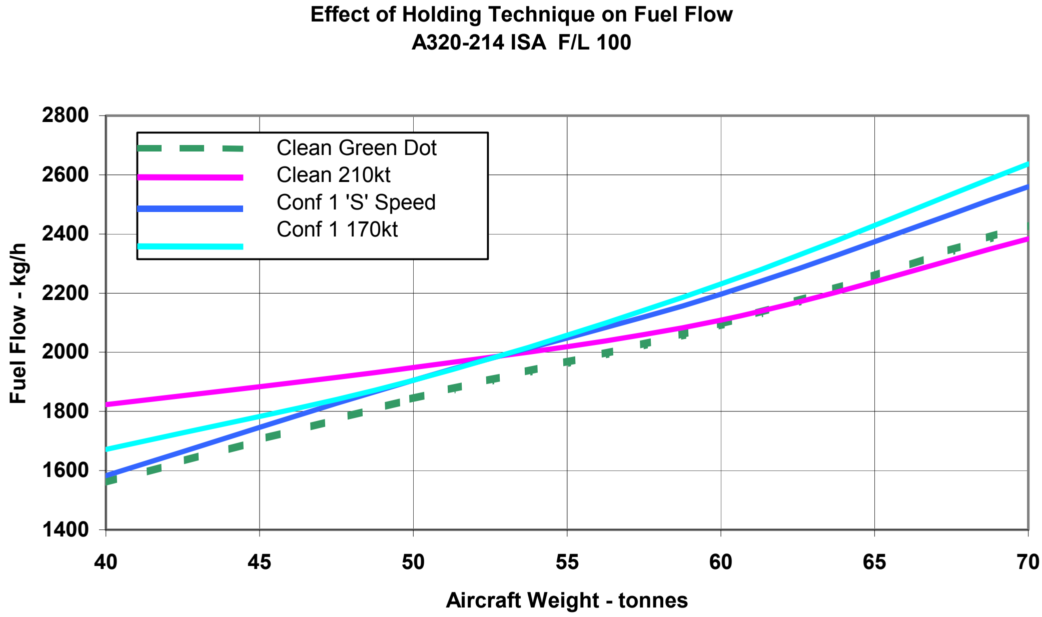
Effect of Holding Technique on Fuel Flow
A310-324 ISA F/L 100



Each configuration shows very similar fuel flow, whichever speed technique is used. The clean configuration green dot speed still represents the best single choice for lowest fuel burn over the normal holding weight range.

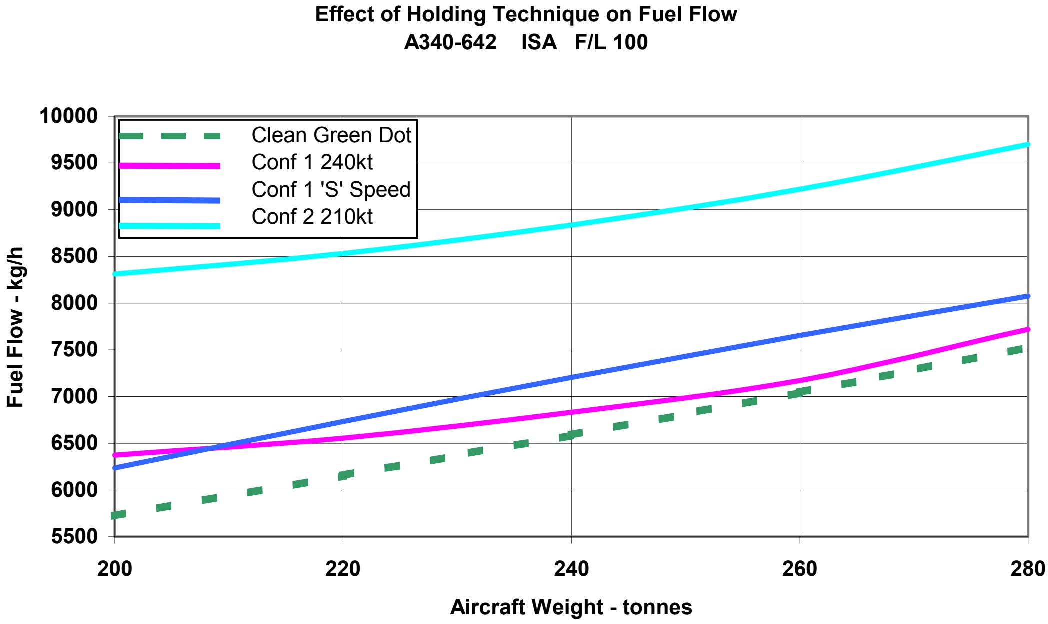
The **A330**, which has the same hold speed schedules shows the same characteristics, with clean configuration at green dot speed being marginally better than clean configuration at 210kt over the normal holding weight range.

The **A320** family shows a completely different set of characteristics as shown in the graph on the next page.



The variation of different techniques is very weight sensitive. However it is still the clean configuration at green dot speed that gives the lowest fuel flow. This picture is typical of all the A320 family.

Finally the **A340-500/600** has another set of configuration/speed combinations and the following graph shows its different characteristics, but the basic concept that the clean configuration and green dot is the best combination still remains true.



There is also **altitude** to be considered, although it is often not the operator's decision what flight level to hold at. Altitude has different effects on the fuel flow, depending on the airframe/engine combination. However, whatever the altitude effect, it generally affects all techniques equally; generally the higher the hold altitude the lower the fuel flow. This however is true only up to a certain altitude and this varies with each type.

The following table shows this altitude effect for a hold in the clean configuration at green dot speed. The holding fuel flow is compared with the lowest for the flight levels considered for each type, and the difference expressed as a percentage.

Flight Level	50	100	150	200	250	300	350	400
A300B4-605R	4	2	1	0	3	8	16	
A310-324	11	5	2	0	0	5	9	23
A318-111	13	8	4	2	1	0	0	5
A319-112	19	11	3	1	0	1	0	4
A320-214	13	5	3	1	1	1	0	2
A320-232	7	5	5	5	2	0	4	11
A321-211	14	11	8	3	0	1	5	
A330-203	2	1	0	0	2	4	8	18
A330-223	9	9	5	2	0	1		14
A340-343	10	5	1	0	0	2	7	16
A340-212	3	2	0	0	2	3	5	
A340-313E	2	1	0	0	2	3	5	
A340-642	6	2	0	1	2	3	4	11

In order to allow an assessment of the sensitivity of each aircraft type to different hold techniques, the following table shows the **extra fuel** required to hold for 15 minutes at 10000ft in the first flap configuration at 'S' speed, compared to Conf clean at green dot speed.

Effect of Holding in First flap Setting at 'S' speed compared with Clean at Green Dot speed

Aircraft types	Fuel Increase (kg) Low Holding Weight	Fuel Increase (kg) High Holding Weight
A300B4-605R	70	110
A300B4-622R	110	190
A310-324	70	135
A318	5	10
A319	10	30
A320	10	30
A321	30	50
A330-203	135	175
A330-223	175	205
A330-343	145	175
A340-212	170	230
A340-313	125	175
A340-642	130	150

The table shows that the green dot speed/clean configuration combination enables significant savings to be made.

However, green dot speed increases with weight and can become higher than the maximum recommended speeds, which are listed below:

Levels	ICAO	PAN-OPS	FAA	France
Up to 6,000 ft inclusive	230 KT	210 KT	200 KT	220 KT
Above 6,000 ft to 14,000 ft inclusive	230 KT	230 KT	230 KT	220 KT
Above 14,000 ft to 20,000 ft inclusive	240 KT	240 KT	265 KT	240 KT
Above 20,000 ft to 24,000 ft inclusive	265 KT	240 KT	265 KT	240 KT
Above 24,000 ft to 34,000 ft inclusive	265 KT	240 KT	265 KT	265 KT
Above 34,000 ft	M 0.83	240 KT	265 KT	M 0.83

If green dot is higher than these maximum recommended speeds, it is advised to hold in configuration 1 at "S" speed below 20000ft: keeping clean configuration coupled with a speed reduction would save fuel but would decrease the speed margins which are especially important in turbulent conditions.

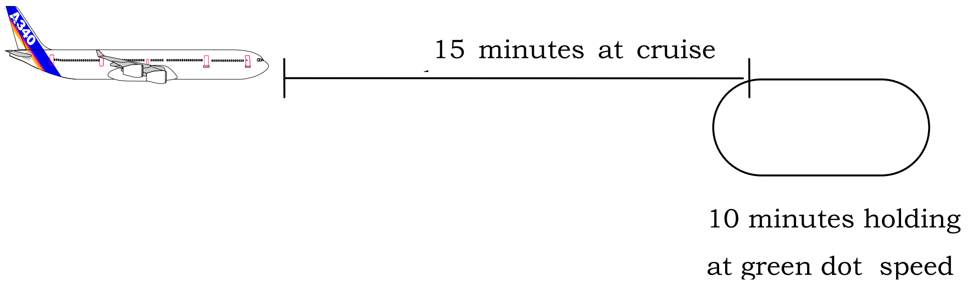
5.5.3 LINEAR HOLDING

If holding is going to be necessary, linear holding at cruise flight level and at green dot speed should be performed whenever possible since total flight time will remain constant (cruise time is increased but holding time is reduced) and fuel flow is lower at high flight levels.

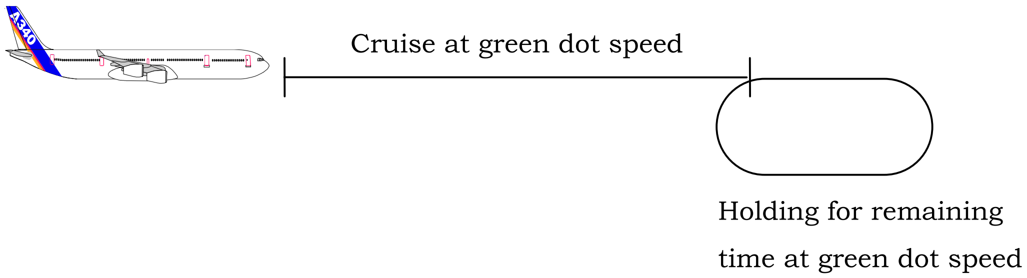
If A.T.C. informs 15 minutes before reaching a fix and that 10 minutes holding is expected. Two options are possible:

- The aircraft is flown 15 minutes at cruise speed and holds for 10 minutes at green dot speed.
- The aircraft performs the cruise to reach the fix at green dot speed and holds for the remaining time at the same speed.

Holding at cruise



Holding optimization



ATC restrictions may not permit a cruise speed reduction at the cruise flight level, or permit a hold at the cruise flight level. The standard procedure would be to continue to the top of descent at cruise speed and descend to a flight level to join the stack. However if ATC permit a linear hold it can give significant fuel savings.

However the amount of savings is very dependant on the characteristics of the aircraft type. The increase in time in the cruise depends on how much slower green dot speed is compared to the normal cruise speed. This increase was much higher with the A320 than the A340. In addition, most aircraft, flying the same cruise distance at green dot speed actually uses a little more fuel at these altitudes. The following table shows the gains due to cruising slower and spending less time in the hold at the cruise flight level.

Advantages of a 15min linear hold at cruise altitude at Green Dot speed

Aircraft type	Weight kg	Cruise Flight Level	Cruise Speed	Fuel savings kg
A300	120000	350	0.8	95
A310	110000	350	0.8	115
A318	50000	350	0.78	120
A319	50000	350	0.78	135
A320	60000	350	0.78	80
A321	70000	350	0.78	50
A330	180000	390	0.82	95
A340-200	200000	390	0.82	10
A340-300	200000	390	0.82	45
A340-500/600	270000	390	0.82	5

The high green dot speed for the A340 leads to very little advantage in linear holding. However the other aircraft show significant benefits.

If the increase in cruise time can be used to reducing the time in the holding pattern or stack, then the benefits will be similar to those shown in the table above. However the constraints of ATC are unlikely to let these benefits accrue.

5.6 APPROACH

5.6.1 FLIGHT PATH PRIOR TO GLIDE SLOPE INTERCEPTION

Procedures used in the approach phase can affect the amount of fuel consumed in this phase of the flight. The glide slope can be intercepted either horizontally between 1500ft and 2000ft or in a descending flight path above 2000ft. This latter method uses less fuel, but the amount is difficult to quantify, as it depends on the exact flight paths in each case. However, the most important feature of an approach is that it should be well executed, stabilized and safe. None of these features should be compromised in an attempt to save fuel, and the procedure flown should be that appropriate to the airport, runway, equipment, conditions, etc.

5.6.2 LANDING GEAR EXTENSION

The standard procedure is that Gear Down is selected down when Conf 2 (or flap 20 for A300/310) is achieved. The effect of extending the gear prior to this point will increase fuel burn, but the amount is difficult to quantify without knowing when the gear is extended. However, the most important feature of an approach is that it should be well executed, stabilized and safe. The use of gear is often one of the means of achieving this through speed control, and gear extension should not be delayed to save fuel.

6. DETAILED SUMMARY

6.1 INTRODUCTION

In this brochure it can be seen that there are many ways of influencing the fuel burn of an aircraft, but most depend on the way that the sector is planned and flown. Maximising the fuel economy requires:

- Good flight planning based on good data.
- Correct aircraft loading (weight and cg).
- An aerodynamically clean aircraft.
- Optimal use of systems (APU, Bleed, Flaps/Slats, Gear, etc).
- Flight Procedures using speeds and altitudes appropriate to the companies economic priorities.
- Use of the FMGS in the managed mode.
- Use of performance factors in flight planning and in the FMGS derived from an ongoing aircraft performance monitoring program.

6.2 GENERAL GUIDELINES

6.2.1 PRE-FLIGHT PROCEDURES

- For most Airbus aircraft, an aft CG position saves fuel.
- Excess weight costs fuel. Minimize zero fuel weight and embarked fuel.
- A good flight planning system will minimise fuel through correct optimisation.
- An aircraft performance measurement system and good flight planning will give confidence in fuel burn reducing extra reserve.
- Keep A.P.U. running during short turnarounds to reduce A.P.U. start cycles.
- Use ground power, when possible to save both fuel and A.P.U. life.

- Do not start engines until ready to go.
- If considered operationally acceptable, taxi with one engine out.
- Keep the aircraft in an aerodynamically clean condition.

6.2.2 TAKE-OFF AND INITIAL CLIMB

- Bleeds off fuel improvements normally negated by APU fuel burn
- Lower configurations do save fuel.
- Flex thrust cost fuel but saves engine costs.
- Noise flight paths cost fuel

6.2.3 CLIMB

- Climb as close as possible to the optimum climb law.
- Fast Climb speeds use more fuel (except A340)

6.2.4 CRUISE

- The best speed for fuel burn (very low cost index) is slow and has a big time penalty.
- If possible, fly in managed mode at the cost index appropriate to the airlines economic priorities.
- Flying faster than the FMGS economical Mach number costs fuel.
- Try to fly at optimum altitude. Chase the optimum altitude.
- Flying at the cross-over altitude is faster, but costs fuel.
- Step Climb around the optimum altitude (see FCOM).
- Avoid delays in initiating a step climb.
- For short stage lengths, fly at an appropriate altitude (see FCOM).
- Wind variations with altitude can give advantages in flying at lower altitudes.

6.2.5 DESCENT

- Diminishing descent speed can allow significant fuel savings.
- Avoid early descents

6.2.6 HOLDING

- The best combination for fuel burn is clean configuration at green dot speed.
- Manoeuvrability, speed or ATC restrictions may require a hold in configuration 1 at S speed.
- If holding is to be anticipated, linear holding saves fuel.

6.2.7 APPROACH

- Avoid extending gear unnecessarily early.

6.3 FUEL SAVINGS

The following table gives examples of the savings possible through the application of correct procedures and practices. The values represent typical saving as there is variation dependant on the actual base case considered. However these figures serve to illustrate the magnitude of savings being achieved (or penalties being paid). The savings are expressed in kg of fuel for one flight, with the sector length being representative for each aircraft.

Fuel Savings Possible in the Pre-Flight phase

Item	Variation	A300	A310	A320	A330	A340-200/300	A340-500/600
Sector		2000nm	2000nm	1000nm	4000nm	6000nm	6000nm
CG	mid to aft	710	330	0	600	900	1550
Weight	-1% MTOW	380	250	100	800	1530	1920
EO Taxi	8 minutes	50	40	25	50	50	70
APU	3 min Grd Power	9	9	6	10	10	14
Ground Idle	3 min APU	18	18	9	15-24	3	9
Misrigged Slat	15mm to zero	90	90	60	270	270	270
Peeling Paint	1sq m slat to zero	12	12	8	60	60	60

Fuel Savings in the In Flight Phase

Item	Variation	A300	A310	A320	A330	A340-200/300	A340-500/600
Sector		2000nm	2000nm	1000nm	4000nm	6000nm	6000nm
TO Conf	Max to min F/S	15	15	10	24	-	50
Climb Rating	Derate 2 to full Climb	NA	NA	NA	30	120-320	445
Climb Speed	330 to 300kias	10	15	70	35	25	-10
Cruise Altitude	Optimum to −2000’	65	80	80	100	95	135
Cruise Altitude	Optimum to +2000’	90	60	25	145	30	25
Cruise Mach	Mecon+.01 to Mecon	230	430	40	330	900	2540
Delayed Climb	CFP to 500nm late	240	220	180	330	390	340
CG	mid to aft	710	330	0	600	900	1550
Descent Speed	Max to 300kt	35	40	30	70	75	100
Early Descent	CFP to 2min early	70	70	50	80	95	135
Hold	Green Dot Clean Conf	190	135	30	205	230	130

6.4 ECONOMIC BENEFITS

It may be that 5 or 10 kg extra fuel per flight does not seem significant in terms of the total fuel burn during the flight. However this saving accumulates with every flight. Sometimes the savings for an A340 seem worthwhile compared with the equivalent value for an A320, but the increased number of flight cycles for an A320 can make this saving more significant than that of the A340. The only way to assess the impact of any saving is to look at it over a given time span.

The economic impact calculations have assumed typical yearly utilisation rates, average sector lengths and sectors per year as follows:

Utilisation	A300	A310	A320	A330	A340
Flying Hours/year	2600	3200	2700	2900	4700
Average sector - nm	2000	2000	1000	4000	6000
Average flight time - hr	4.5	4.6	2.4	8.5	13.8
No of sectors/year	580	700	1125	340	340

The following table shows the annual cost savings for one aircraft associated with various fuel savings for each Airbus type based on the above utilisation figures. Fuel is assumed to cost $1/us gallon (33cents/kg).

Savings/flight	A300	A310	A320	A330	A340
10kg	$1920	$2310	$3720	$1120	$1120
50kg	$9600	$11550	$18600	$5600	$5600
250kg	$48000	$57750	$93000	$28000	$28000
1000kg	$192000	$231000	$372000	$112000	$112000

7. CONCLUSIONS

There are many factors that influence the fuel used by aircraft, and these are highlighted in this report. The unpredictability of fuel prices, together with the fact that they represent such a large burden to the airline has prompted Airbus to be innovative in the field of fuel conservation. The relationship between fuel used and flight time is such that sometimes compromise is necessary to get the best economics. Whether in the field of design engineering or in flight operations support, we have always maintained a competitive edge. Whether it is in short or ample supply, we have always considered fuel conservation a subject worth revisiting.

Fuel conservation affects many areas including flight planning, flight operations and maintenance. Airbus is willing and able to support airlines with operational support in all the appropriate disciplines. Despite the increasing efficiency of modern aircraft it is a subject that demands continuous attention and an airline that can focus on the subject, together with the Operation Support of Airbus is best placed to meet the challenges of surviving and profiting in the harsh airline environment of the 21^{st} century.

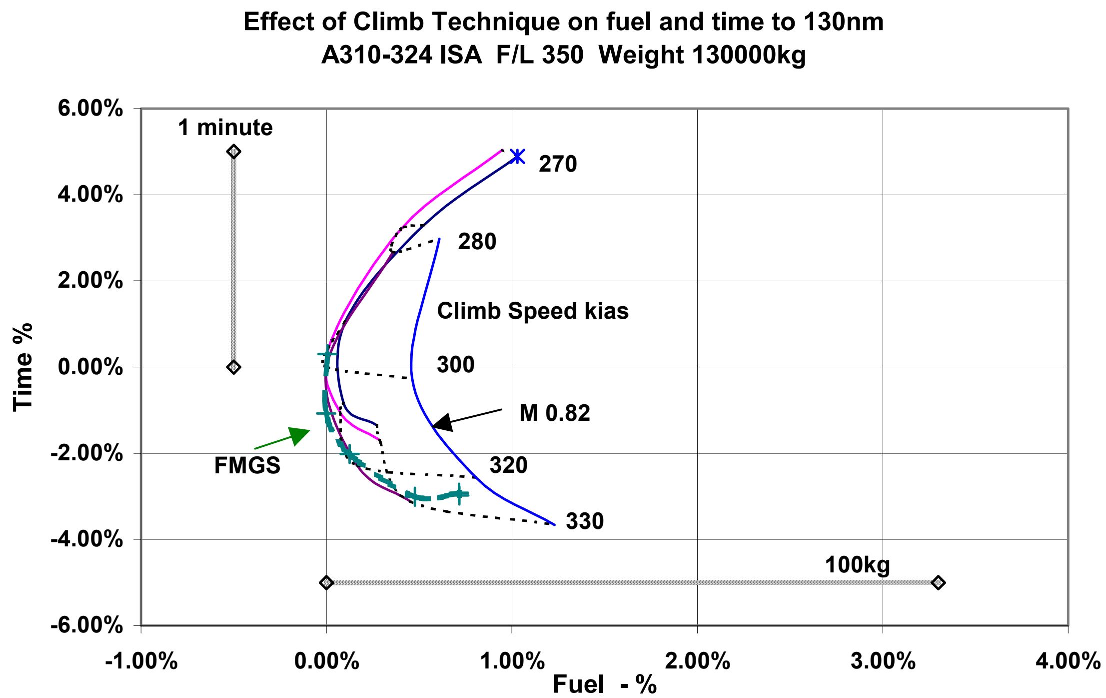
8. APPENDICES

These appendices contain climb and descent graphs for some of the other variants of Airbus aircraft. Each airframe/engine combination have different characteristics. Even the weight variant can influence these characteristics. It is therefore impossible to include all variants, but the selection shown will give an idea of the sensitivities of fuel burn and time to technique.

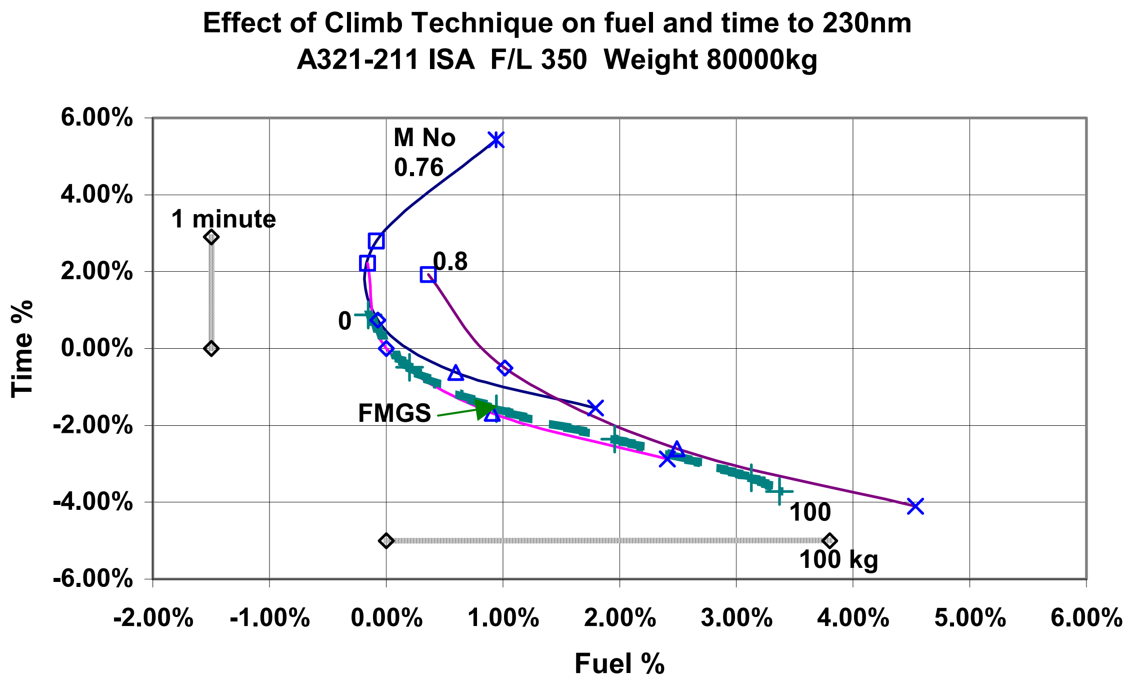
APPENDIX A (CLIMB CHARTS)

The climb chart for the A300 is given in the main report (5.2.3)

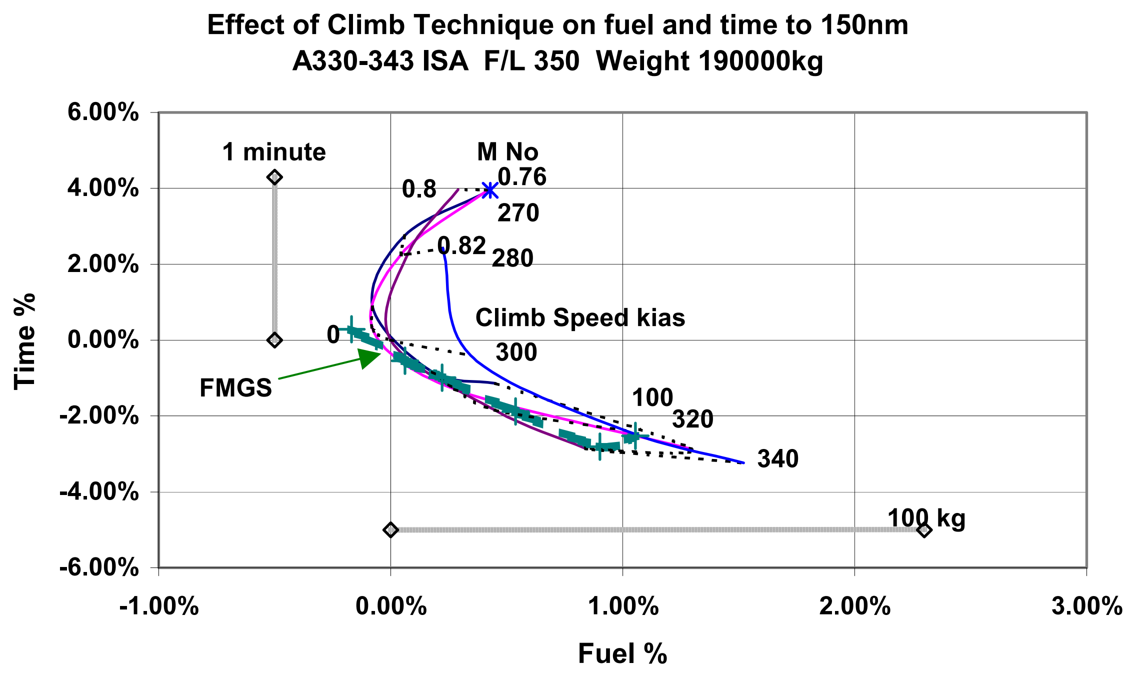
The **A310** shows similar characteristics and is shown below. Note that the lower mach numbers (0.76, 0.78 and 0.8) show no variation.



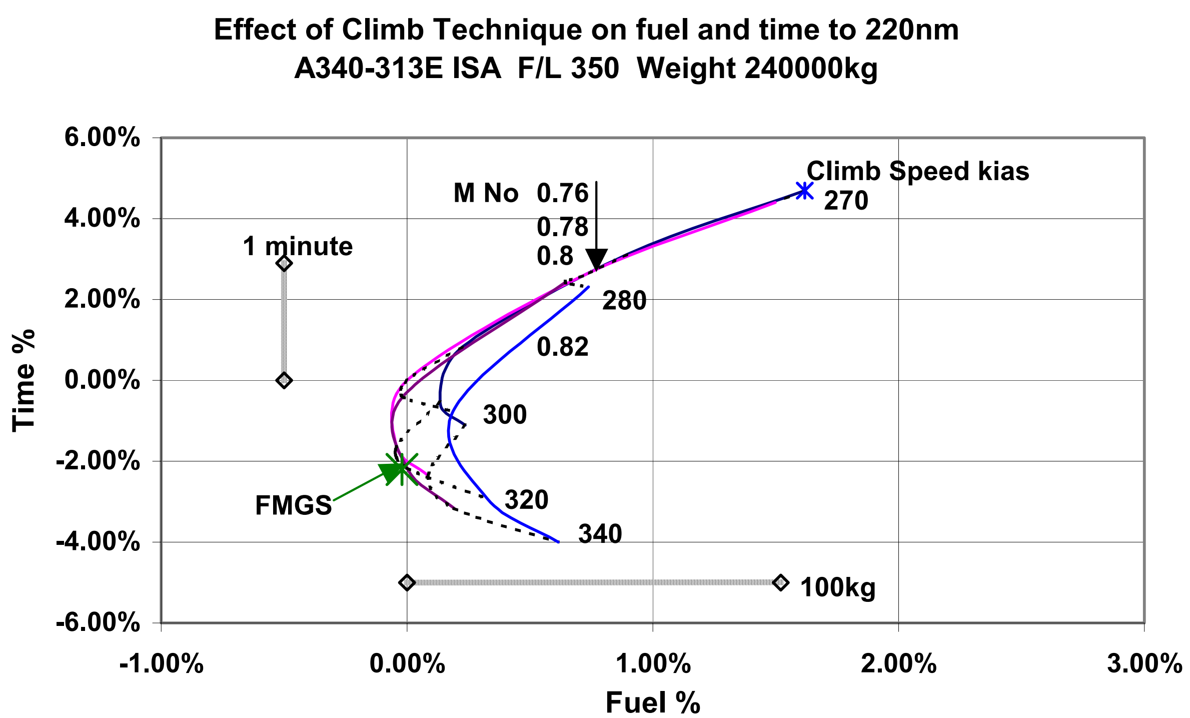
The main report gives the climb chart for the A320 which is similar to the A318 and A319. The **A321** however shows more significant differences.



The **A330** aircraft show characteristics similar to the A321 and an example is shown below.

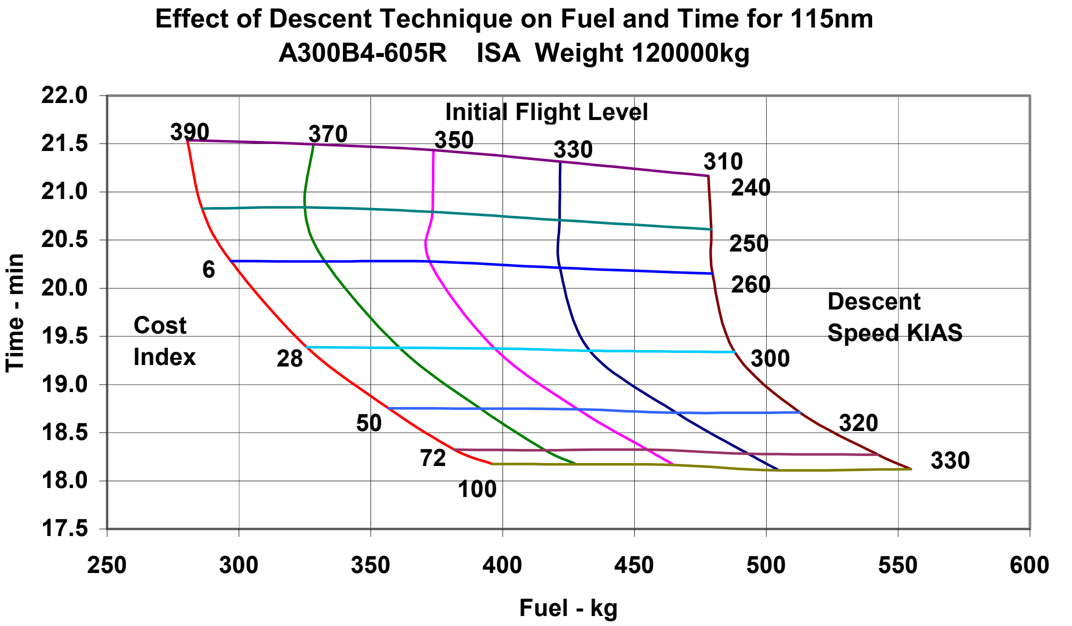


The **A340-200/300** series show characteristics approaching that of the A340-500/600 but still shows minimum fuel at a speed lower than max, unlike the A340-500/600 (see 5.2.3).

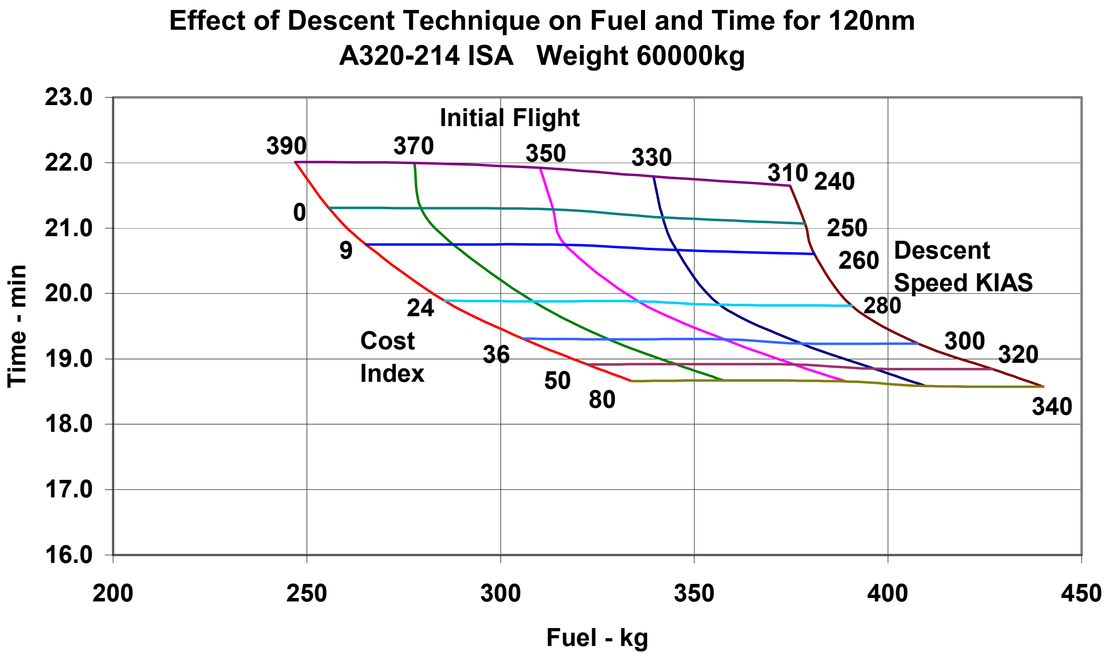


APPENDIX B (DESCENT CHARTS)

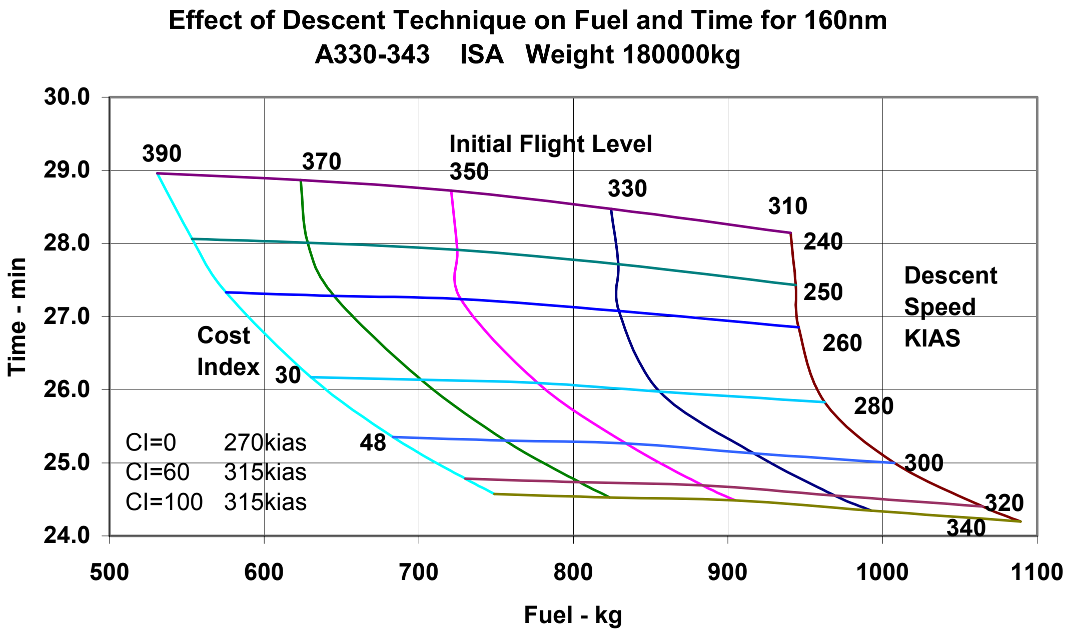
The **A300** shows similar characteristics to the A310 in the main report.



The **A320** shown below has similar characteristics to the A318, A319 and A321.



The following shows an example of an **A330**:



Most of the **A340**'s have similar speed characteristics to the A340-642 shown below. The A340-200 does however show an improvement in fuel for speeds lower than 260kts.