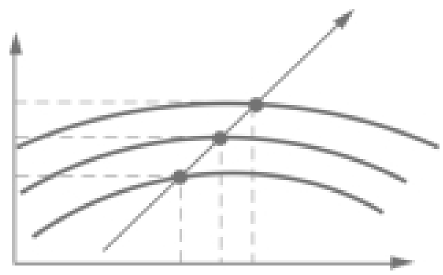
Flight Operations Support and Line Assistance



getting to grips with

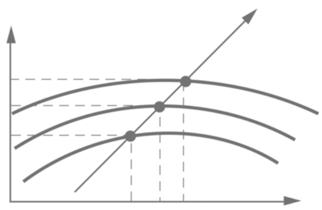
aircraft performance monitoring

Customer Services

AIRBUS

Flight Operations Support & Line Assistance

Customer Services
1, rond-point Maurice Bellonte, BP 33
31707 BLAGNAC Cedex FRANCE
Telephone (+33) 5 61 93 33 33
Telefax (+33) 5 61 93 29 68
Telex AIRBU 530526F
SITA TLSBI7X



getting to grips with aircraft performance monitoring

December 2002

FOREWORD

The purpose of this brochure is to provide airline flight operations with some recommendations on the way to regularly monitor their aircraft performance.

This brochure was designed to provide guidelines for aircraft performance monitoring based on the feedback obtained from many operators and on the knowledge of Airbus aircraft and systems.

Should there be any discrepancy between the information given in this brochure and that published in the applicable AFM, FCOM, AMM or SB, the latter prevails.

Airbus would be eager to work with some airlines on an ongoing application of this projected performance monitoring system well in advance of its anticipated use on the A380 program.

Airbus encourages to submit any suggestions or remarks concerning this brochure to:

AIRBUS
CUSTOMER SERVICES DIRECTORATE
Flight Operations & Line Assistance - STL
1, rond point Maurice Bellonte
BP33
31707 BLAGNAC Cedex
FRANCE

Fax : + 33 (0) 61 93 29 68/44 65
TELEX : AIRBU 530526 F

TABLE OF CONTENTS

A. INTRODUCTION

For years, the business environment has become more and more challenging. Yields are dropping while competition is increasing. Business traffic is volatile, aircraft operations are becoming more and more expensive and spare parts are changing faster and faster. Airlines are faced with new objectives to adapt to this environment.

Fuel burn contributes up to ten percent to direct operating costs. Engine maintenance is up to another quarter. The operator's main concern is therefore to have a high quality information about the condition and the performance of the aircraft whenever needed.

That’s why Airbus feels deeply involved in aircraft performance monitoring and has been proposing for years some tools for aircraft performance monitoring as well as some guidelines to perform aircraft performance audits.

Today’s aeronautics industry has been undeniably dominated by generation and acquisition of large amounts of data in all airline departments. In particular, airline flight operations have been staggering under a high flow of data. The key point in this massive data flow is to identify what is needed and for what purpose.

Amongst this huge flow of data, some may be used to monitor the performance of a given airplane and/or of the whole fleet. Long term trend monitoring of the aircraft performance really takes place in the frame of maintenance actions and complements all other monitoring methods.
Likewise, aircraft performance monitoring involves the whole company:

- Flight crew and flight operations staff members are the primary source of information. Indeed, data acquisition and analysis is one of their responsibilities.
- Maintenance staff members play a role in the process, as keeping the aircraft in the best condition possible is their main concern. Tracking of non-clean surfaces, monitoring of the engine performance, calibration of airspeed/Mach number/altitude is their responsibility.
- Management offices are also involved for their awareness, directives and funding of the whole process.

This booklet has a five-field purpose. First, it will introduce performance monitoring, presenting the different analysis methods and tools. Second, as a consequence of the amount of data required for analysis, the most common ways to get data routinely recorded are detailed, through a quick overview of the available aircraft systems. Third, it will give some guidelines on the way to process the data thanks to one of the Airbus aircraft performance-monitoring tool, namely the APM program. The fourth part will help assessing data coming from regular cruise performance analysis. Finally, it will give Airbus recommendations on the way to us the results the analysis in daily aircraft operations.

A glossary at the end of the document gives a definition of the terms used in this brochure. Finally, there is a list of documents in the bibliography that may help in the interpretation of the results of the various types of analyzes.

B. BACKGROUND

The purpose of this chapter is to provide a basic knowledge on aircraft performance monitoring. The method used for analysis as well as the appropriate tools are detailed here below.

This brochure is focused on the specific range method and on the utilization of the APM program. This chapter also gives some information on other methods that can be used for cruise performance analysis.

1. WHAT IS PERFORMANCE MONITORING?

Aircraft performance monitoring is performed in the frame of fuel conservation and of aircraft drag assessment. It is a procedure devoted to gathering aircraft data in order to determine the actual performance level of each airplane of the fleet with respect to the manufacturer's *book level*.

The *aircraft performance book level* is established by the aircraft manufacturer and represents a fleet average of brand new airframe and engines. This level is established in advance of production. Normal scatter of brand new aircraft leads to individual performance above and below the book value. The performance data given in the Airbus documentation (Flight Crew Operating Manual) reflects this book value. The high-speed book value data is stored in the high-speed performance databases used by Airbus performance software such as the IFP, the FLIP or the APM programs.

The performance levels are measured in their variations over time. Resulting trends can be made available to the operators' various departments, which perform corrective actions to keep a satisfactory aircraft condition.

The actual aircraft performance deterioration endows two main origins: engine performance degradation (fuel consumption increase for a given thrust) and airframe deterioration (seals, doors, slats and flaps rigging, spoilers rigging, etc...). A starting point is required so as to monitor the trend of the performance deterioration. The *baseline level* is an aircraft performance level retained as a reference to get the trend of aircraft performance deterioration. Most of the time the baseline is established at the aircraft entry into service during the first flight or delivery flight. The baseline can be above or below the book level as a result of above-mentioned scatter.

2. AIM OF THE AIRCRAFT PERFORMANCE MONITORING

Results of aircraft performance monitoring are used to reach the following objectives:

- To adjust the performance factor for:
  - the computerized flight plan,
  - the FMS predictions and

- To monitor the aircraft condition periodically in order to analyze the trend of a given tail number or of a whole fleet,

- To identify the possible degraded aircraft within the fleet and take care of the necessary corrective actions:
  - Maintenance actions
  - Route restrictions

- To demonstrate the performance factor for ETOPS which may be used instead of the 5% factor imposed by regulations.

It also allows operators to perform various statistics about fuel consumption and as such is a good aid to define the operators' fuel policy.

As a general rule, regulation requires to take into account "realistic" aircraft fuel consumption.

3. THE CRUISE PERFORMANCE ANALYSIS METHODS

There are mainly three methods to compare actual aircraft performance level to the book value:

1. The fuel used method,

2. The fuel on board method,

3. The specific range method.

This chapter is focused on the specific range method. For further details about the two other methods, read *Chapter H - Appendices*.

This subject was already presented during the 7th Performance and Operations Conference held at Cancun, Mexico in year 1992. This brochure is based upon the leading article "Auditing aircraft cruise performance in airline revenue service" presented by Mr. J.J. SPEYER, which was used as reference material.
This article is appended at the end of this brochure, see *Chapter 0 - Appendix 6 - Auditing aircraft cruise performance in airline revenue service*.

3.1. The fuel used method

The basis of the fuel used method is to measure aircraft fuel burnt in level flight and over a significantly long time leg and to compare it to the fuel prediction of the Flight Crew Operating Manual (FCOM, Flight Planning sections) or of the High Speed Performance calculation program developed by Airbus (the IFP program).

This method probably provides less information than the specific range method but is also less constraining in terms of stability and data acquisition requirements. The method is also less accurate because of the lack of stability checks on the observed data.

3.2. The fuel burn off method

The trip fuel burn analysis compares genuine aircraft performance data for a whole flight with the forecasted computerized flight planning. Actual aircraft performance should be corrected depending on the differences between the actual flight profile and the predicted one.

3.3. The specific range method

3.3.1. Introduction

The data observed in flight represents punctual (instantaneous) airframe/engine performance capability. It is used to generate a measured Specific Range, which represents the actual aircraft fuel mileage capability (NM/kg or lb of fuel). The specific range represents the aircraft/engine performance level under stabilized conditions and thus constitutes the main reference criterion. It may not be representative of the actual fuel consumption of the aircraft during a whole flight.

3.3.2. Definition

The **specific range** (**SR**) is the distance covered per fuel burn unit.
Basically, the specific range is equal to:

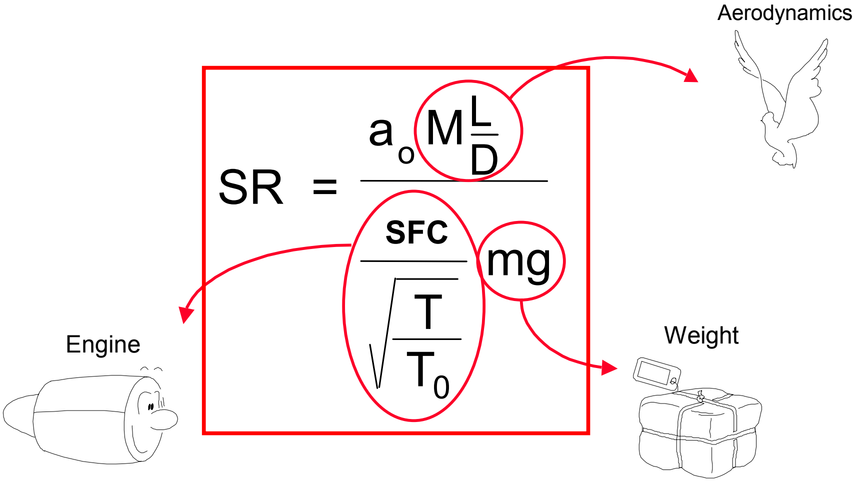
$$\boxed{SR_{\text{(Ground)}} = \frac{\text{ground speed (GS)}}{\text{fuel consumption per hour (FF)}}}$$

Considering air distance, the specific range is equal to:

$$\boxed{SR_{\text{(Air)}} = \frac{\text{true air speed (TAS)}}{\text{fuel consumption per hour (FF)}}}$$

As TAS is expressed in nautical miles per hour (NM/h), and Fuel Flow (FF) in kilograms per hour (kg/h), the SR is expressed in NM/kg or NM/ton.

Moreover, SR depends on aerodynamic characteristics (Mach number and lift-to-drag ratio), engine performance (Specific Fuel Consumption)[1], aircraft weight (mg) and sound velocity at sea level (a_0).



$$SR = \frac{a_o M \frac{L}{D}}{\frac{SFC}{\sqrt{\frac{T}{T_0}}} mg}$$

Figure B0 - Illustration of the contributors on the Specific Range

Where SR is the Specific Range in NM/kg
a_0 is the celerity of sound at sea level in m/s
M is the Mach Number
L/D is the lift-to-drag ratio
SFC is the Specific Fuel Consumption
M is the aircraft mass in kg
T is the static air temperature in degrees Kelvin
T_0 is the static air temperature in degrees Kelvin at sea level

M . L/D ↗	⇨	SR ↗
m ↗	⇨	SR ↘
SFC ↗	⇨	SR ↘

3.3.3. Principle of the method

The following parameters is determined based on data recorded during stable cruise flight legs:

- the actual specific range,
- the delta (difference in) specific range in percentage relative to the book level (predicted specific range),
- the delta EPR/N1 required to maintain flight conditions,
- the delta fuel flow resulting from this delta EPR/N1,
- the delta fuel flow required to maintain this delta EPR/N1.

[1] Specific Fuel Consumption (SFC) is equal to the fuel flow (FF) divided by the available thrust. It is expressed in kg/h.N (kilogram per hour per Newton) and represents the fuel consumption per thrust unit.

The predicted specific range can be obtained thanks to Airbus featured software:
- The In-Flight Performance calculation program (IFP) or
- The Aircraft Performance Monitoring program. This program effectively compares recorded data with the performance book level.

This predicted specific range corresponds to the book level. It is consistent with the FCOM performance charts.

The specific range method is the only technique, which enables to assess the respective contribution of the airframe and the engines in the observed delta specific range, even though utmost precautions must be taken when doing so.

3.3.4. How to obtain Specific Range

In the FCOM, cruise tables are established for several Mach numbers in different ISA conditions with normal air conditioning and anti-icing off. Basic aircraft performance levels are presented in Figure B1 on next page.

A319/320/321	IN FLIGHT PERFORMANCE	3.05.15	P 9
FLIGHT CREW OPERATING MANUAL	CRUISE	SEQ 110	REV 31

R

CRUISE - M.78

MAX. CRUISE THRUST LIMITS NORMAL AIR CONDITIONING ANTI-ICING OFF	ISA CG=33.0%	N1 (%) KG/H/ENG NM/1000KG	MACH IAS (KT) TAS (KT)

WEIGHT (1000KG)	FL290		FL310		FL330		FL350		FL370		FL390	
50	84.0	.780	84.0	.780	84.0	.780	84.1	.780	84.7	.780	85.9	.780
	1276	302	1189	289	1112	277	1044	264	992	252	955	241
	180.9	462	192.5	458	204.0	454	215.4	450	225.6	447	234.1	447
52	84.2	.780	84.2	.780	84.3	.780	84.5	.780	85.1	.780	86.3	.780
	1288	302	1202	289	1127	277	1060	264	1011	252	977	241
	179.2	462	190.3	458	201.4	454	212.0	450	221.3	447	229.0	447
54	84.4	.780	84.5	.780	84.6	.780	84.8	.780	85.5	.780	86.9	.780
	1300	302	1216	289	1142	277	1079	264	1031	252	1003	241
	177.5	462	188.1	458	198.6	454	208.4	450	217.0	447	223.1	447
56	84.7	.780	84.8	.780	84.9	.780	85.2	.780	85.9	.780	87.6	.780
	1314	302	1231	289	1159	277	1097	264	1052	252	1036	241
	175.7	462	185.9	458	195.7	454	204.8	450	212.6	447	216.0	447
58	84.9	.780	85.1	.780	85.2	.780	85.6	.780	86.4	.780	88.3	.780
	1328	302	1246	289	1176	277	1117	264	1075	252	1070	241
	173.9	462	183.6	458	192.8	454	201.3	450	208.1	447	209.0	447
60	85.2	.780	85.3	.780	85.6	.780	85.9	.780	86.9	.780	89.2	.780
	1342	302	1262	289	1195	277	1137	264	1102	252	1110	241
	172.0	462	181.3	458	189.8	454	197.6	450	203.0	447	201.5	447
62	85.5	.780	85.6	.780	85.9	.780	86.3	.780	87.6	.780	90.1	.780
	1357	302	1279	289	1214	277	1158	264	1135	252	1153	241
	170.1	462	178.8	458	186.8	454	194.1	450	197.1	447	194.0	447
64	85.7	.780	85.9	.780	86.2	.780	86.7	.780	88.2	.780		
	1373	302	1297	289	1234	277	1182	264	1170	252		
	168.2	462	176.4	458	183.8	454	190.2	450	191.2	447		
66	86.0	.780	86.2	.780	86.6	.780	87.2	.780	89.0	.780		
	1389	302	1316	289	1254	277	1209	264	1209	252		
	166.2	462	173.9	458	180.9	454	186.0	450	185.0	447		
68	86.2	.780	86.5	.780	86.9	.780	87.8	.780	89.8	.780		
	1406	302	1335	289	1275	277	1242	264	1252	252		
	164.2	462	171.4	458	177.9	454	181.0	450	178.7	447		
70	86.5	.780	86.8	.780	87.3	.780	88.4	.780	90.8	.780		
	1424	302	1355	289	1299	277	1277	264	1298	252		
	162.1	462	168.9	458	174.6	454	176.1	450	172.3	447		
72	86.8	.780	87.1	.780	87.7	.780	89.0	.780				
	1442	302	1375	289	1325	277	1314	264				
	160.0	462	166.4	458	171.2	454	171.1	450				
74	87.1	.780	87.5	.780	88.2	.780	89.8	.780				
	1462	302	1397	289	1357	277	1356	264				
	157.9	462	163.9	458	167.1	454	165.7	450				
76	87.4	.780	87.8	.780	88.8	.780	90.5	.780				
	1482	302	1419	289	1392	277	1400	264				
	155.8	462	161.3	458	162.9	454	160.5	450				

LOW AIR CONDITIONING	ENGINE ANTI ICE ON	TOTAL ANTI ICE ON
△FUEL = − 0.5 %	△FUEL = + 2 %	△FUEL = + 5 %

Figure B1: Cruise table example for a particular A320 model

3.4. Corrections and precautions

In order to establish a valid comparison between observed data and the applicable book level, one should clearly identify the following items. A few approximations may indeed lead to an apparent deterioration, which may significantly alter the analysis of the actual performance deterioration.

3.4.1. Operational factors

The intent of the following is to describe the potential factors that can occur during normal aircraft operations and which may have an adverse effect on the cruise performance analysis in terms of systematic error or random error.

3.4.1.1. Assumed gross weight deviation

The aircraft gross weight deviation may be originating from three different sources.

3.4.1.1.1. Operating Weight Empty (OEW)

Error on the Operating Empty Weight (OEW) can be caused by the normal increase of the OEW due to the incorporation of modifications, and dust and water accumulation. This error may amount to a few hundred of kilograms after several years.

Both the JAA and the FAA impose that operators regularly establish and verify aircraft weight to account for the accumulated weight due to repairs and/or aircraft modifications. For more information on requirements and means, read JAR-OPS 1.605 or FAA AC 120-27C.

3.4.1.1.2. Cargo hold weight

Cargo hold weight can be biased due to unweighted cargo and/or unaccounted last minute changes.

3.4.1.1.3. Passenger and baggage weights

Errors on passenger weights are usually due to underestimations of both passenger and hand luggage weights. JAA and FAA have each published some material to define and regulate the estimation of passenger and baggage weights. The following reminds main statements extracted from the JAR-OPS and from the FAR.

JAR-OPS guidelines

The JAA has produced specific JAR-OPS requirements on passenger and baggage standard weights: JAR-OPS 1.620. This paragraph proposes that, for the purpose of calculating the weight of an aircraft, the total weights of passengers, their hand baggage and checked-in baggage entered on the load sheet shall be computed using either:

- Actual weighing just prior to boarding (if the flight should be identified as carrying excessive weights) or
- Standard weight values. Male/female passenger standard weights can be used alternatively to all-adult standard weights. Refer to tables below.

Type of flight	Male	Female	Children (2~12 years old)	All adult
All flights except holiday charters	88 kg 195 lb	70 kg 155 lb	35 kg 77 lb	84 kg 185 lb
Holiday charters	83 kg 183 lb	69 kg 152 lb	35 kg 77 lb	76 kg 168 lb

Table B1 - JAR-OPS Standard passenger weights including hand baggage

Note : Infants below 2 years of age would not be counted if carried by adults on passenger seats, and would be regarded as children when occupying separate passenger seats.

Type of flight	Baggage standard mass
Domestic	11 kg 24 lb
Within the European region	13 kg 29 lb
Intercontinental	15 kg 33 lb
All other	13 kg 29 lb

Table B2 - JAR-OPS Standard weight values for each piece of checked-in baggage

Available data does not show large differences between summer and winter weights. No difference was therefore made. Short-haul flights are predominantly used by businessmen travelling without checked-in baggage. On long-haul flights, there are obviously less “hand baggage only “passengers. The non-scheduled “summer holiday” passenger is generally lighter and carries less hand baggage.

In practice, although the male/female ratio depicts large variations, there are many flights with significantly less than 20% female passengers, and there are not a lot of high quality surveys available. Therefore a conservative ratio of 80 / 20 was retained for determining the present all-adult standard weight value of 84 kg on scheduled flights. For non-scheduled flights (76 kg) a 50 / 50 ratio was chosen. Any variation from these ratios on specific routes or flights would have to be substantiated by a survey-weighing plan.

The use of other standard weights is also considered in the JAR-OPS:

- A suitable statistical method is given in Appendix 1 to JAR-OPS 1.620(g) for verification or updating of standard weight values for passengers and baggage, should an airline choose to prove other weights by looking into its own operations. This would involve taking random samples, the selection of which should be representative of passenger volume (weighing at least 2000 pax), type of operation and frequency of flights on various routes. Significant variations in passenger and baggage weights must clearly be accounted for. Anyway, a review of these weights would have to be performed every five years, and the load sheet should always contain references to the weighting method hereby adopted.

- Results of the airline weighing survey should then be validated and approved by the Authority before the airline-standard weight actually becomes applicable.

FAR guidelines

The FAA has issued an Advisory Circular (ref. AC 120-27C) to provide methods and procedures for developing weight and balance control. Similarly to JAR-OPS, it also involves initial and periodic re-weighting of aircraft (every 3 years) to determine average empty and actual operating weight and CG position for a fleet group of the same model and configuration. The following standard average weights were adopted and are reminded in the following tables.

Type of flight	Male	Female	Children (2~12 years old)	All adult
Summer flights (from May, 1st till October, 31st)	88 kg 195 lb	70 kg 155 lb	36 kg 80 lb	82 kg 180 lb
Winter flights (from November 1st till April, 30th)	91 kg 200 lb	73 kg 160 lb	36 kg 80 lb	84 kg 185 lb

Table B3 - AC 120-27C Standard passenger weights including hand baggage

Notes: 1. Infants below 2 years of age have already been factored into adult weights.

2. The above weight values include 10 kg/20 lb carry-on baggage for adult passengers.

Type of flight	Baggage standard mass
Domestic	11 kg 25 lb
International and non-scheduled	14 kg 30 lb

Table B4 - AC 120-27C Standard check baggage weights

When passengers belong to a very specific group such as athletic squads, soccer teams… the actual weight of the group should be retained.

Similarly to JAA and FAA requests, airlines have to adopt standard weights unless they request different values, which would have to be proven by a weighing survey at the risk of ending up with higher statistics. Regional exceptions would be allowed when substantiated by means of an accepted methodology.

3.4.1.1.4. Impact on monitored aircraft performance

The impact of these regulatory stipulations on cruise mileage is evident. An underestimation of the aircraft gross weight is considered to result in an apparent increase of fuel used and in a decrease of specific range. It causes apparent airframe degradation. A bias on the analysis result is often observed.

3.4.1.2. Airframe maintenance and aerodynamic deterioration

One of the penalties in terms of fuel mileage is an increased drag due to the poor airframe condition of the aircraft. Normal aerodynamic deterioration of an aircraft over a given period of time can include incomplete retraction of moving surfaces, or surface deterioration due to bird strikes or damages repairs. Each deterioration induces increased drag and as a consequence increased fuel consumption.

The induced fuel burn penalty largely depends on the location of the drag-inducing item. These items can be classified in several groups, depending on their location on the aircraft. The aircraft can be split into three main areas from the most critical one to the less critical one. This zones depend on the aircraft type. The complete description of these zones is given in a separate Airbus brochure (refer to *Chapter J-Bibliography, document [J-3]*).

Routine aircraft performance monitoring performed using the Airbus APM program can help detecting a poor aircraft surface condition. Although APM results have to be interpreted with lots of care, it can trigger an alarm for induced drag increase.
Of course, this approach is a first step approach that can be confirmed by means of a visual inspection of the aircraft surface, and though direct measurements in the suspected area as detailed in the Airplane Maintenance Manual (AMM).

If the APM program is not used but another method, it could be worth implementing an aerodynamic inspection for example at the occasion of a C check.

In order to complement cruise performance analyses, and whenever possible, the aircraft should be observed on ground (to be confirmed with photographs) and in flight for any surface misalignment or other aerodynamic discrepancies such as:

- door misrigging (see figure B3)
- missing or damaged door seal sections
- control surface misrigging (see figure B2)
- missing or damaged seal sections on movable surfaces
- skin dents and surface roughness
- skin joint filling compound missing or damaged.

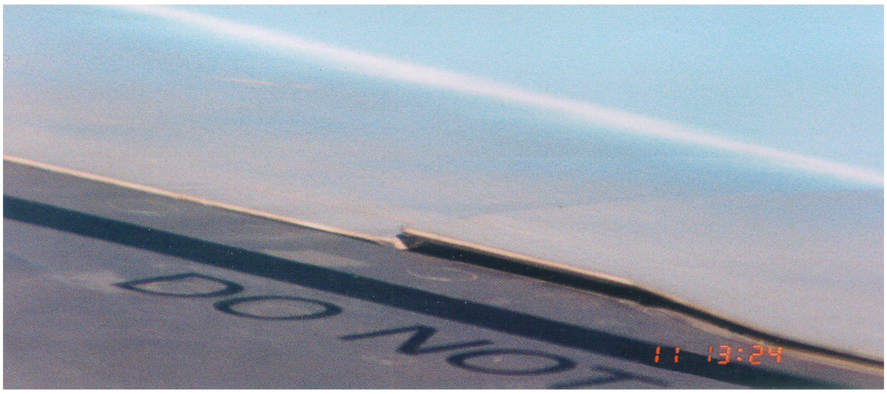


Figure B2 - Example of misrigged slat

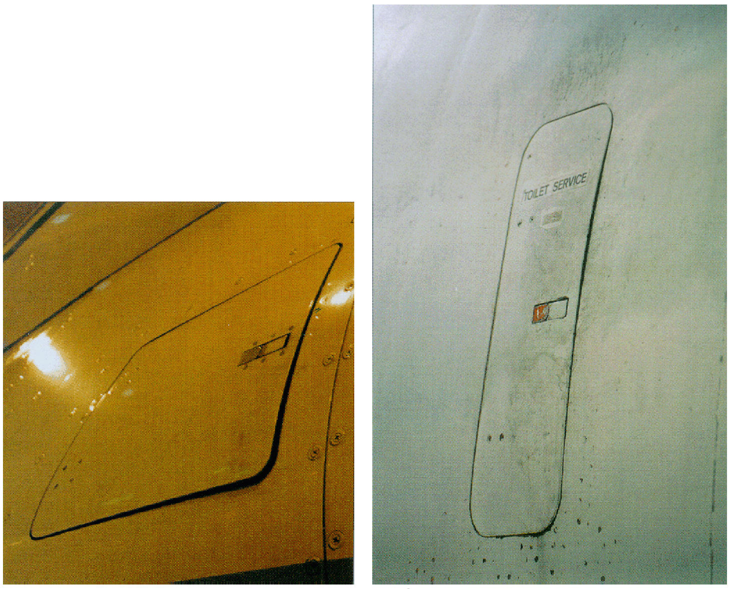


Figure B3 - Example of misrigged doors

In flight this would specifically pertain to :
- slats alignment and seating
- pylons and pylon – to – wing interfaces
- engine cowlings
- spoilers trailing edge seating and seal condition (rubber or brush)
- flaps, flap tabs and all-speed ailerons trailing edge alignment.

On ground this would specifically pertain to most forward and middle areas:
- Static and dynamic pitot condition
- Nose radome misalignment
- Cargo door to fuselage alignment
- Service door condition
- Engine fan blade condition (curling, etc).
- Surface cleanliness (hydraulic fluid, dirt, paint peeling (see figure B4), etc).
- Under-wing condition
- Wing-body fairing
- Nose and main landing gear door adjustment
- Temporary surface protection remnants.

Figure B4 - Paint Peeling

Figure B5 shows an example of a very unclean aircraft. This parasitic drag assessment shows an estimated amount of 6.09 extra drag count resulting in a 2%-loss of Specific Range.

More details on that subject is available in another Airbus publication “Getting hands on experience with Aerodynamic deterioration” (see *Chapter J-Bibliography, document [J-3]*).

Control surface mis-rigging

Control surface	Estimated percentage of increased drag for surface misrigging – Height 5 mm	10 mm	15 mm	Corrective action (inspection + rigging)	AMM reference	Man hours	Check interval
SLAT	0.09%	0.2%	0.3%	Adjustment of slats	27-80-00	2 per slat	
				Folding nose adjustment Fairing plate adjustment Krueger flap adjustment Notch flap adjustment Movable vane adjustment	27-81-33 p. 403 27-81-34 p. 402 27-81-58 p. 903, 904, 905 27-87-11 p. 406, 407 (A300, A300/600) 27-87-00 p. 501, 505 (A310) 27-87-13 p. 405 (A300, A300/600) 27-87-12 p. 405		Visual inspection A-check
FLAP	0.04%	0.07%	0.1%	Adjustment of flaps	27-50-00	3 per flap	Rigging : C-check
				Movable fairings flap tr F adjustment	27-50-21 p. 406, 408		
Spoiler	0.1%	0.23%	0.36%	Adjustment of spoilers	27-61-00 p. 501	2 per spoiler	
Aileron	0.04%	0.07%	0.1%	Adjustment of all speed ailerons	27.11.00 p. 501	4 per aileron	
Rudder	0.05%	0.09%	0.12%	Adjustment of rudder	27-21-00 p. 501	3	
Elevator				Adjustment of elevators	27-31-00 p. 501		
THS				THS adjustment	57-10-11		

GENERIC EXAMPLE

. Middle slat section :
LH (15 mm forward step) : $\Delta C_d = 0.46\ d_c$
RH (10 mm forward step) : $\Delta C_d = 0.33\ d_c$

. Aft facing step, entire middle slat section :
LH (1 mm) : $\Delta C_d = 1.42\ d_c$
RH (0.8 mm) : $\Delta C_d = 0.9\ d_c$

. Inner-Mid slat junction aft step both wings :
(5 mm by 50 cm wide) : $\Delta C_d = 2 \times 0.22\ d_c$
or $= 0.44\ d_c$

. All Speed Ailerons : both
(0.5° inboard angle tilt) : $\Delta C_d = 2 \times 0.5\ d_c$
or $= 1.0\ d_c$

. Spoiler Upfloat :
LH (1 with 2 mm step) : $\Delta C_d = 0.18\ d_c$
RH (3 with 5 mm steps) : $\Delta C_d = 1.32\ d_c$

. Nose Radome step :
(2 mm by 1.7 m circumference) :
$\Delta C_d = 0.016\ d_c$

. Inspection hatch behind RH wing :
(20 cm x 20 cm, fwd step 2 mm) : $\Delta C_d = 0.002\ d_c$
aft step 1 mm) : $\Delta C_d = 0.001\ d_c$

. Cargo door dents :
(1.5 cm x 20 cm) : $\Delta C_d = 0.015\ d_c$

. Toilet Service Door :
(3 mm step x 10 cm) : $\Delta C_d = 0.001\ d_c$

. Service Door :
(2 mm step x 10 cm) : $\Delta C_d = 0.001\ d_c$

Estimated extra drag counts : 6.09
Estimated DFF / DSR penalty : 2.0 %

Parasitic Drag Assessment Example

Figure B5 - Parasitic Drag Assessment example for an A310 aircraft

3.4.1.3. Aircraft trimming and asymmetry diagnosis (BIAS)

Accurate and repetitive trimming allows to identify the origin of small but persistent asymmetries to be identified especially on A300B2/B4 and A310 / A300-600 aircraft.

The reasons for these asymmetries can be several:
- General production tolerances, particularly wing tolerances and asymmetry between both wings in dimensions, wing / fuselage local setting, wing twist
- Control surface rigging tolerances, particularly for rudder, ailerons and spoilers,
- Fuel loading asymmetries between both wings, although displayed FQI values are symmetrical
- Thrust setting asymmetries between both engines, although displayed N1 / EPR values are symmetrical
- Cargo or passenger loading asymmetries.

All of these could lead to an aircraft not flying straight in cruise with all lateral / directional control surfaces in perfectly neutral positions.

On A310/A300-600 aircraft, Airbus recommends to laterally trim an asymmetrical aircraft with the zero control wheel technique because it is less fuel consuming than any other technique.

On fly-by-wire aircraft, the flight control system compensates almost 100% for changes of trim due to changes in speed and configuration. Changes in thrust result in higher changes in trim and are compensated for by changing the aircraft attitude.

The apparent drag, resulting from a lateral asymmetry of the aircraft will bias cruise performance analysis. On A310/A300-600, an aircraft lateral asymmetry can result in a 0.3% deterioration of the specific range.

Procedures for checking the aircraft lateral symmetry are given in the Flight Crew Operating Manual:
- In section 2.02.09 for A310 and A300-600 aircraft types
- In section 3.04.27 for fly-by-wire aircraft

3.4.1.4. Bleed and pressurization (BIAS)

Cabin air leakage may result in increased engine bleed extraction (for the same thrust) and aerodynamic flow losses. This is most of the time of second order influence but in some cases it should be closely monitored and carefully corrected (whenever possible) so as to decrease the bias on the analysis.

Selecting anti-ice and measuring cruise performance can also give a useful comparison with anti-ice off. The nominal extra fuel consumption at flight conditions can be calculated from the IFP and can be compared with the measured difference in fuel consumption / SR with and without anti-ice. For those cases where this measured difference is below the nominal difference, it can be hypothesized that some bleed leaks in the anti-ice ducts may be at the origin of engine fuel flow deviation with anti-ice off. This test is performed for qualitative purposes only, and suggests the possibility of leaks without necessarily estimating the extent or amount of actual engine deviation.

For the purpose of performance monitoring, Airbus recommendations are to fly in as stabilized conditions as possible. In particular, the bleed configuration should be as follows to have the data collected:

- anti ice OFF
- air conditioning NORM

Additionally, asymmetrical bleed configuration must be avoided to get relevant data for analysis. In case of asymmetrical bleed configuration, no data is automatically recorded via the Data Management Unit (DMU) or via the Flight Data Interface and Management Unit (FDIMU).

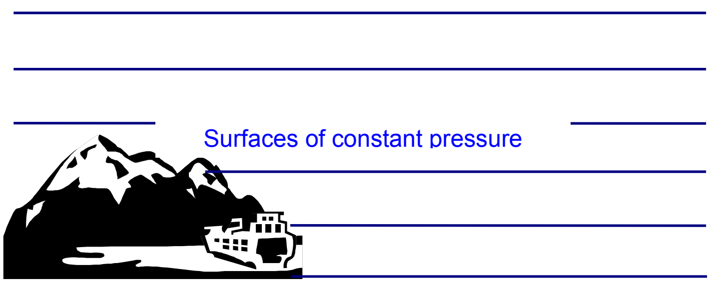
3.4.2. Environmental factors

Weather is one natural phenomenon that man has not yet learnt to reliably predict, although accuracy is really increasing. Weather has of a critical influence on aircraft performance and on the outcome of the flight operations.

The intent of the following is to describe potential factors often encountered and may have a significant effect on cruise performance analysis in terms of scatter.

3.4.2.1. Isobaric slope due to pressure gradient

The International Standard Atmosphere (ISA) model assumes that the pressure decreases with altitude. This model is a very reliable law, enabling to represent temperature, pressure, density of the atmosphere, depending on the altitude.



The surfaces of constant pressure are supposed horizontal.
These surfaces are not modified by terrain.

Figure B8 - Isobaric-pressure surfaces

Aircraft fly in cruise at given pressure altitude, with a common pressure reference, which is agreed worldwide: 1013 hPa. That common reference makes sure all aircraft are correctly separated when flying and ensures common language is used between all the different aircraft and between the aircraft and the Air Traffic Controls.
Altitudes given in Flight Level (e.g. FL350) refer to the 1013 hPa isobar.

Of course, the principle shown in figure B8 is theory. When an aircraft flies over long ranges, the weather conditions change continuously. In particular, at a given geometric height, pressure varies. Or the other way around, for a particular pressure, the geometric height will for sure vary.

Therefore, when flying along an isobaric line,

- In LP zones, the aircraft actually descends relative to lifting air in order to maintain pressure altitude. Hence aircraft performance is slightly better than reality (since Mach number slightly increases).
- In HP zones, the aircraft actually climbs relative to lifting air in order to maintain the pressure altitude. Thus, the aircraft performance is slightly worse than reality (since Mach number slightly decreases).

The aircraft vertical velocity can be estimated from the wind and pressure forecast maps at a given FL and on a given sector. On this type of maps (see Figure B9), Isobaric or iso-altitude lines are indicated. As a reminder, 1 hPa near the ground is equivalent to 28 feet while 1 hPa at FL380 is equivalent to 100 feet.

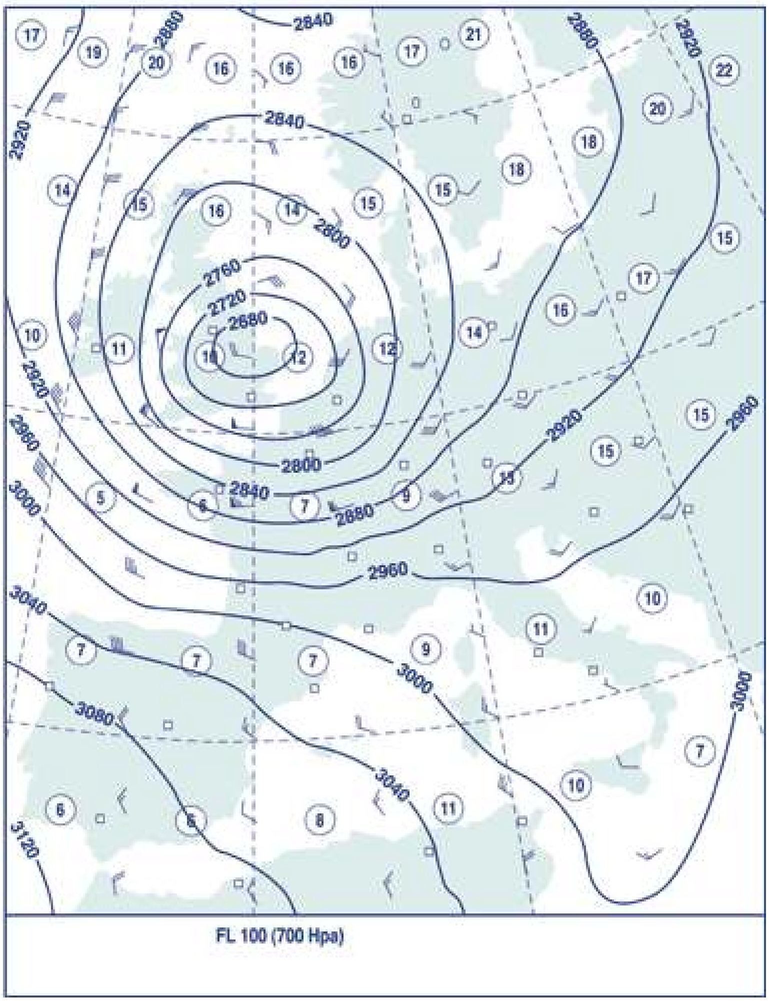


Figure B9 - Isobars FL100/700 hPa - iso-Altitudes, temperatures and winds

Weather offices can provide isobars at different altitudes, indicated in Flight Levels (FL): FL50/850 hPa, FL100/700 hPa, FL180/500 hPa, FL250/300 hPa, FL340/250 hPa, FL390/200 hPa.

Thus, as a result of the isobaric surface slope, the aircraft may be flying uphill or downhill depending on the pressure field. In performance demonstration flight test, isobars are usually followed to minimize drift angle. In airline revenue service, this is not feasible since airways cut across the isobars.

The isobaric slope can be related to the drift angle as illustrated on figure B10.

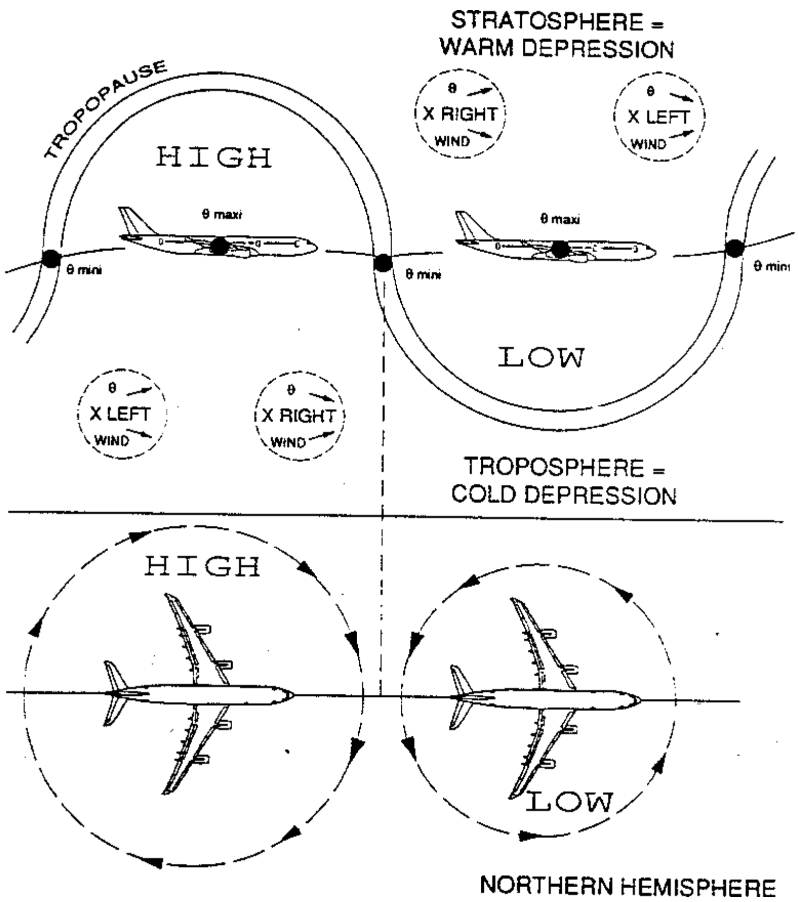


Figure B10 - Isobaric slope and drift angle

In the Northern Hemisphere:

- Right Hand (RH) drift angle corresponds to wind from the left.
  The aircraft is flying towards a low pressure, i.e. it is flying downhill,
    * In the troposphere, SAT decreases / wind increases
    * In the stratosphere, SAT increases / wind decreases
- Left Hand (LH) drift angle corresponds to wind from the right
  The aircraft is flying towards a high-pressure zone, i.e. it is flying uphill,
    * In the troposphere, SAT increases / wind decreases
    * In the stratosphere, SAT decreases / wind increases

The opposite phenomenon prevail in the Southern Hemisphere.

Wind velocity increases below the tropopause and decreases above the tropopause by approximately 5% per 1000 ft except in jet stream zones. Near the tropopause, the wind velocity is maximum.

In order account for the isobaric slope, the aircraft should be given a bonus when flying uphill (LH drift angle in Northern Hemisphere, RH drift angle in Southern hemisphere) and a penalty when the aircraft is flying downhill (RH drift angle in Northern hemisphere, LH drift angle in Southern hemisphere).

The correction is applied on the $\frac{\Delta SR}{SR}$ (or $-\frac{\Delta FU}{FU}$) as follows:

$$\boxed{\left(\frac{\Delta SR}{SR}\right)_{CORR} = -\left(\frac{\Delta FU}{FU}\right)_{CORR} = -1.107\times10^{-2}\times TAS\times\sin(LAT)\times\tan(DA)}$$

where TAS is the true airspeed in knots
DA is the drift angle
LAT is the latitude

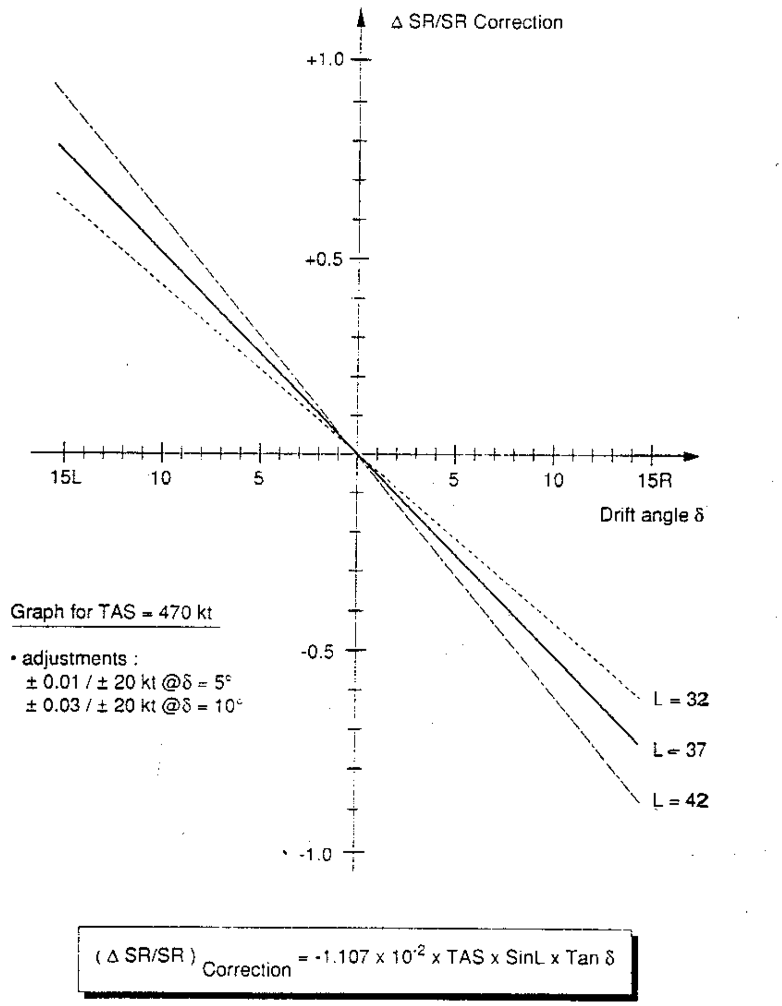


Figure B11 - Example of SR deviation correction

In practice, drift (track-heading), temperature (SAT) and wind observations (direction/speed) allow to consider:

- Pressure patterns (high and lows)
- Wind barbs (direction/speed / FL)
- Tropopause height
- Stratospheric lapse rate
- Temperature trends around tropopause
- Jetstream core locations
- Turbulence

In any case the aircraft must be stabilized (Flight Path Acceleration, Vertical Velocity).

Whilst carrying out an aircraft performance monitoring audit, one would refrain from taking stabilized cruise performance readings if the pressure system is changing rapidly or when drift angles are greater or equal to 5 degrees. Very often, a positive ΔT can be observed ($\cong$ 10° C in horizontal flight) when passing through the tropopause from the troposphere to the stratosphere. This temperature increase is even more noticeable when the tropopause slope angle is steep and therefore when wind velocity is highest at the point where the tropopause is passed through.

The equation in Figure B11 is valid only for high-altitude winds; less-than ideal conditions like topographic effects (mountain waves) or strong curvature for the isobars > 5° drift would lead to erroneous results.

3.4.2.2. Isobaric slope due to the temperature gradient

The International Standard Atmosphere (ISA) model assumes pressure decreases with altitude. This model is a very reliable law, enabling to represent temperature, pressure, and density of the atmosphere, depending on the altitude.

From the ground up to the tropopause, the mean temperature decreases continuously with altitude (see figure B12 on next page).

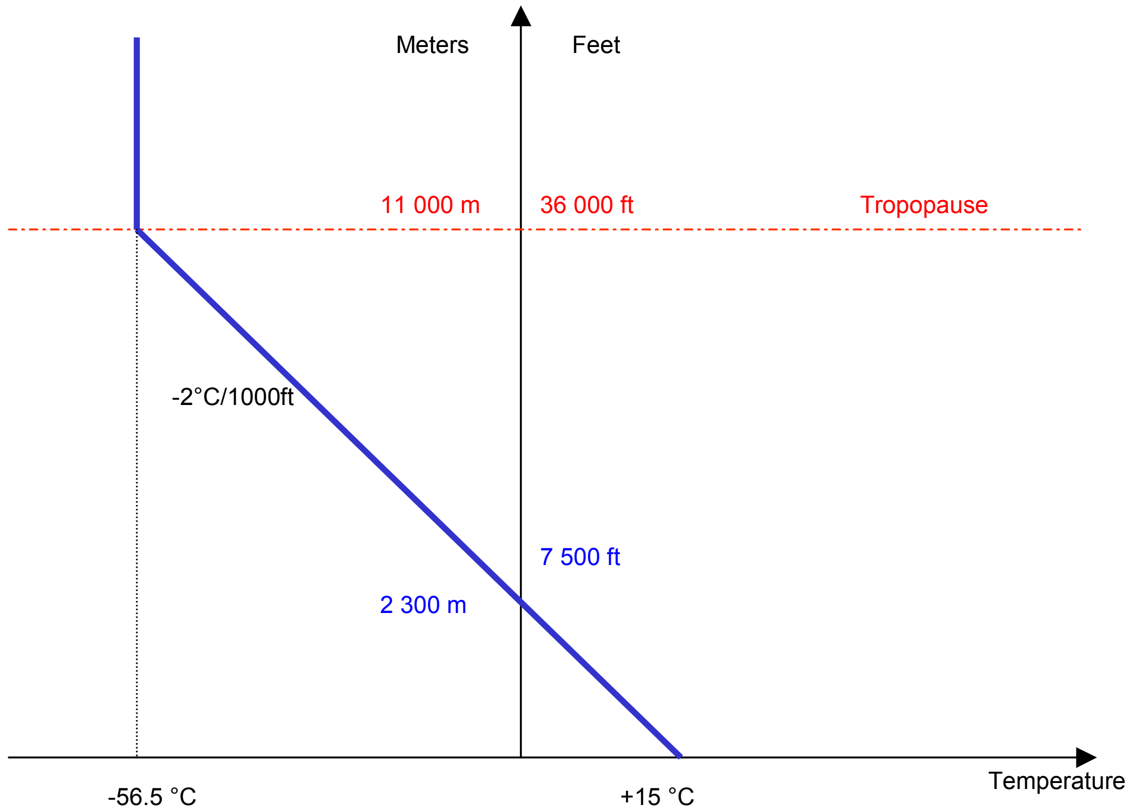


Figure B12 - ISA Temperature model

Indeed, in the real world, at a given FL, the temperature changes continuously. Engine efficiency depends on the difference between the fuel temperature (in fuel tanks, the temperature is fixed) and the outside air temperature (static temperature, SAT). In cruise, if the SAT increases, engine thrust decreases and vice-versa. The autothrust corrects this in order to maintain the pressure altitude. Recordings should be performed in a zone where the SAT is forecasted stable.

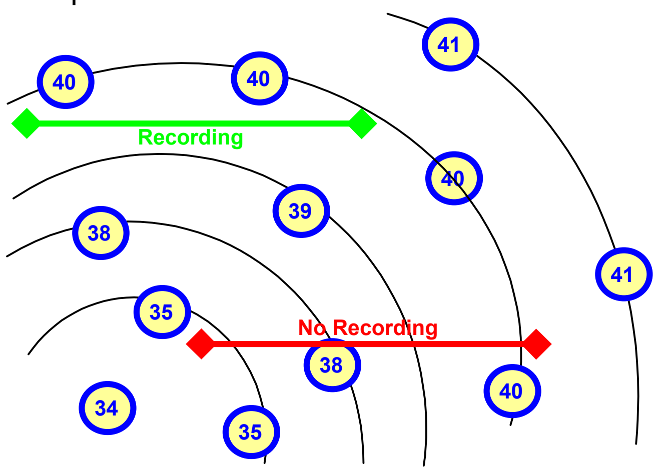


Figure B13 - Stable Temperature zone

For aircraft performance monitoring purposes, the autothrust being disengaged, the SAT variation should be limited to 1°C during the actual data recording leg.

In order to verify the influence of the temperature gradient on aircraft performance, the following should be considered. Temperature gradients also modify the slope of the isobaric surfaces. For example, low-pressure areas are cold compared to high-pressure areas but the colder the low pressure, the steeper the isobaric surface slope.

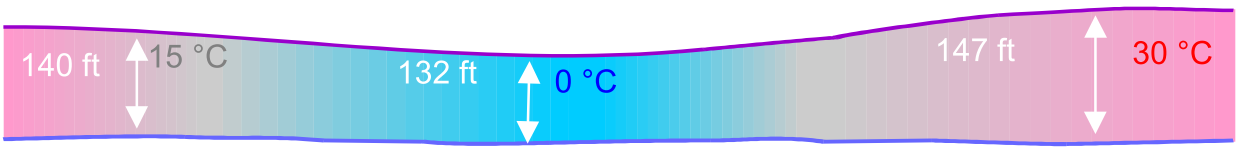
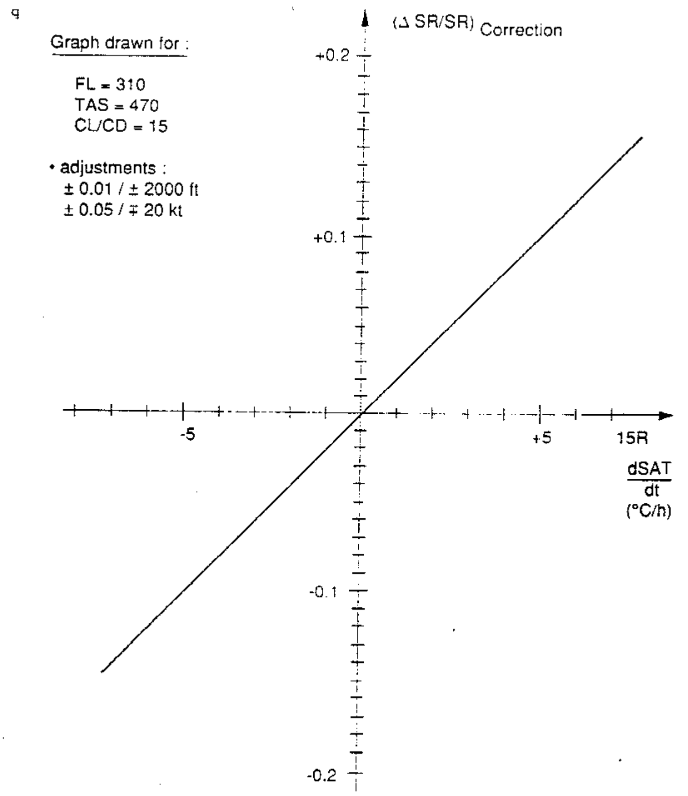


Figure B14 - Illustration of the isobaric slope due to the temperature

In order to compensate for the modified isobaric slope, the aircraft will be given a bonus or a penalty depending on the temperature gradient, and as follows:

$$\boxed{\left(\frac{\Delta SR}{SR}\right)_{CORR} = 9.4\times10^{-3}\times(0.25\times FL-11.5)\times\frac{C_L}{C_D}\times\partial SAT\times\frac{1}{TAS}}$$

A graphic example is given in following Figure B15.



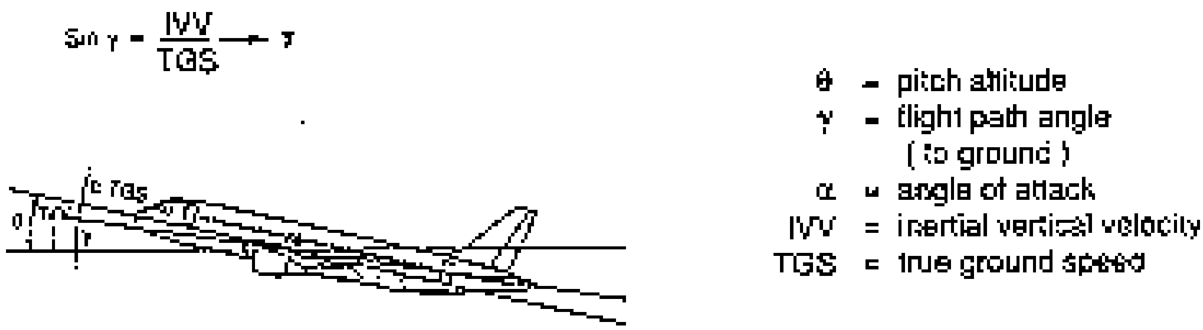
$$\boxed{(\Delta SR/SR)_{Correction} \doteq 0.0094\times(0.25FL-11.5)\times\frac{C_L}{C_D}\times\frac{1}{TAS}\times dSAT}$$

Figure B15 - Example of graphical result

Note: The usefulness of these isobaric slope corrections is, in fact, rather questionable since the theoretical assumptions are usually not applicable to the real atmosphere. What we are looking for is the change in potential energy represented:

- *by the slope of the flight path, and / or*
- *by the change of geopotential altitude*

However, when performing an assessment of this slope through the observed drift, and/or temperature trend, only the conditions between, earth's surface and flight altitude are relevant ; this applies for both the assessment of the pressure-related slope as well as for a temperature related slope. There is presently no system which is capable of sensing flight path slope with the required accuracy (better than 0.002°).



The only valuable approach today is to compute this slope from inertial information. This then would include all possible isobaric slope effects (pressure or temperature, geostrophic winds) without having to distinguish between those.

3.4.2.3. Winds and Pressure zones

Let us start with basic reminders on winds and pressure zones.

3.4.2.3.1. Wind

At high altitudes, the wind direction follows isobaric lines, while at low altitudes, the wind direction cuts through isobaric lines.

As illustrated on figure B15bis, when crossing over isobaric lines, and when in the North hemisphere (the contrary for South hemisphere),

- if left hand wind, the aircraft flies from a high pressure zone to a low pressure zone
- if right hand wind, the aircraft flies from a low pressure zone to a high pressure zone

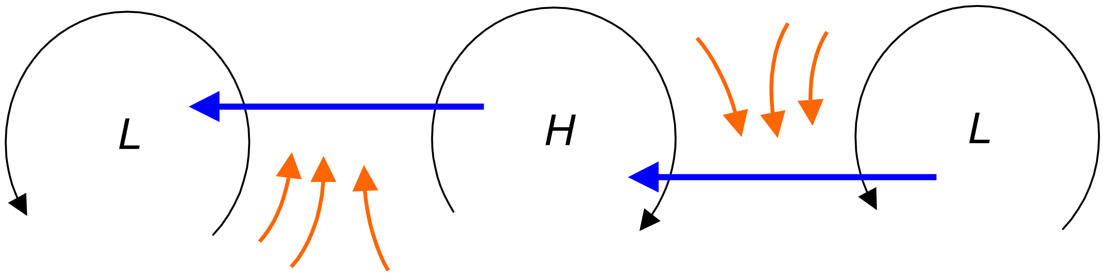


Figure B15 bis - Wind / Pressure zones relationship

3.4.2.3.2. Pressure versus wind relationship

Pressure variations are linked to the wind velocity. Indeed,

- Low wind velocity corresponds to slow pressure variations
- High wind velocity corresponds to quick pressure variations

Thus, at a given flight level or pressure altitude, successive isobaric lines are distant with weak wind, close with strong wind.

As a result, the wind force is linked to the pressure distribution, and as of a consequence, it has an impact on the actual aircraft profile.

3.4.2.4. Low and high pressure zones

The low pressure (LP) zones are small and scattered. The isobaric lines are concentrated and close to circles. In these LP zones, the air is unstable and climbs strongly. Some turbulence may be encountered.

The high pressure (HP) zones are wide. Isobaric lines are distant and have awkward shapes. In these HP zones, the air is stable and gently descents.

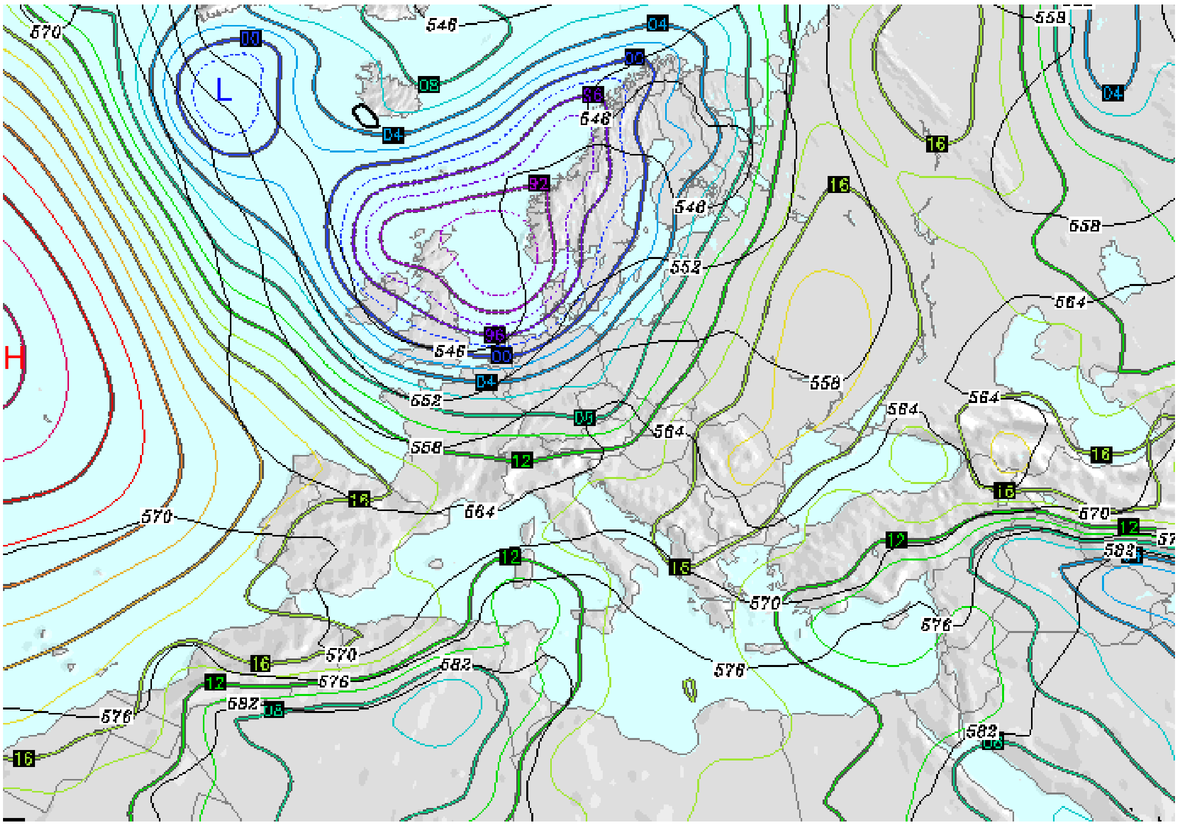


Figure B16 - Example of HP and LP zones

In practice, the air mass vertical velocity cannot be measured on board the aircraft. The aircraft trim is modified to maintain pressure altitude.

In Europe, statistical air vertical velocities encountered are centimetric (from 0.01m/s to 0.1 m/s). Worldwide, the mean value of vertical winds encountered is 0.6 m/second.

Most of the monitoring procedures probably do induce a unfavorable bias in cruise performance measurements because the crew usually concentrates on calm atmospheres. As explained above, extremely calm atmospheres necessarily correspond to sinking zones since these tend to increase stability. The problem is therefore to estimate the bias that can be attributed to vertical winds. As a preliminary study, the specific range deviation generated by an air mass vertical velocity was established on an A320 aircraft model and was equal to a DSR of 1% for 0.17 m/second.

Consequently, to gather data of better quality, recordings should be performed in a mildly agitated atmosphere rather than in a calm zone.

3.4.2.5. The Coriolis effect

The Coriolis effect is the tendency for any moving body on or above the earth's surface to drift sideways from its course because of the earth's rotational direction (west to east) and speed, which is greater for a surface point near the equator than towards the poles.

In the Northern Hemisphere the drift is to the right of the body's motion; in the Southern Hemisphere, it is to the left.

The Coriolis deflection is therefore related to the motion of the object, the motion of the Earth, and the latitude. The Coriolis acceleration results in an increase or decrease of the apparent aircraft gross weight.

$$\boxed{\frac{\Delta GW}{GW} = -7.63 \times 10^{-6} \times GS \times \sin(TT) \times \cos(LAT)}$$

Where GW is the aircraft gross weight
GS is the ground speed in knots
TT is the true track
LAT is the latitude

At a given ground speed and latitude,

- In the Northern Hemisphere, the aircraft gross weight increases when flying westwards and decreases when flying eastwards.
- In the Southern Hemisphere, the aircraft gross weight decreases when flying westwards and increases when flying eastwards.

In order to account for the gross weight deviation, a positive correction when the aircraft is flying westwards and negative correction when the aircraft is flying eastwards (in Northern Hemisphere, and vice versa in the Southern Hemisphere) could be applied to the specific range.

The correction is applied on the $\frac{\Delta SR}{SR}$ as follows:

$$\left(\frac{\Delta SR}{SR}\right)_{CORR} = \frac{\Delta Cd}{Cd} = +k \times \frac{\Delta Cl}{Cl} = +k \times \frac{\Delta GW}{GW}$$

where k is a function of the drag and lift coefficients.

Hence,

$$\boxed{\left(\frac{\Delta SR}{SR}\right)_{CORR} = -k \times 7.63 \times 10^{-6} \times GS \times \sin(TT) \times \cos(LAT)}$$

Where GS is the ground speed in knots
TT is the true track
LAT is the latitude

3.4.3. Technical factors

3.4.3.1. Fuel Lower Heating Value (Fuel LHV)

The Fuel LHV defines the fuel specific heat or heat capacity of the fuel. The usual unit for this parameter is BTU/LB.

Fuel flow is directly impacted by this value. The effect of the fuel LHV on the apparent cruise performance level is explained below thanks to a basic reminder of the operation of a gas-turbine engine.

The engines are required to produce a certain amount of thrust (i.e. a N1/EPR thrust setting parameter is required) to maintain the aircraft in steady cruise level flight. For given flight conditions, a given engine provides an amount of thrust, which depends on the amount of heat energy coming from the fuel burning in the combustion chamber.

The heat energy per unit of time is given by the following formula:

$$Q = J \times Hf \times Wf$$

Where J is physical constant
Hf is the fuel specific heat (Fuel LHV) in BTU[1]/lb
Wf is the fuel flow in lb/h

As a consequence, the fuel flow required to produce a given amount of thrust is:

$$Wf = \frac{Q}{J \times Hf} = \frac{1}{FLHV} \times \frac{Q}{J}$$

The required thrust being fixed, the heat energy Q is also fixed. Thus, **the higher the FLHV, the lower the required fuel flow**.

[1] BTU is the British Thermal Unit. It corresponds to the heat quantity required to increase the temperature of one pound of water from 39.2°F to 40.2°F. 1 BTU = 1.05506 kJ

The following conclusions can be drawn from the above equations:

1. Any deviation in the fuel LHV will result in a deviation in fuel flow

2. As the heat energy remains constant whenever fuel LHV and fuel flow vary, the engine thermodynamic cycle is unchanged. The high-pressure rotor speed N2 and the Exhaust Gas Temperature remain unchanged.

3. The only affected parameters are fuel flow (FF) and specific range (SR).

$$\boxed{\frac{\Delta FF}{FF} = -\frac{\Delta FLHV}{FLHV}} \text{ and } \boxed{\frac{\Delta SR}{SR} = +\frac{\Delta FLHV}{FLHV}}$$

The FLHV local and seasonal variations being a fact of industry, the accuracy can be increased by a FLHV measurement.

It is in any case essential to perform FLHV measurements, as variations in fuel quality exist throughout the world (crude oil quality) and in between flights. Airbus now has a fairly large database we have been receiving lots of samples from our audits worldwide as shown in figure B17.

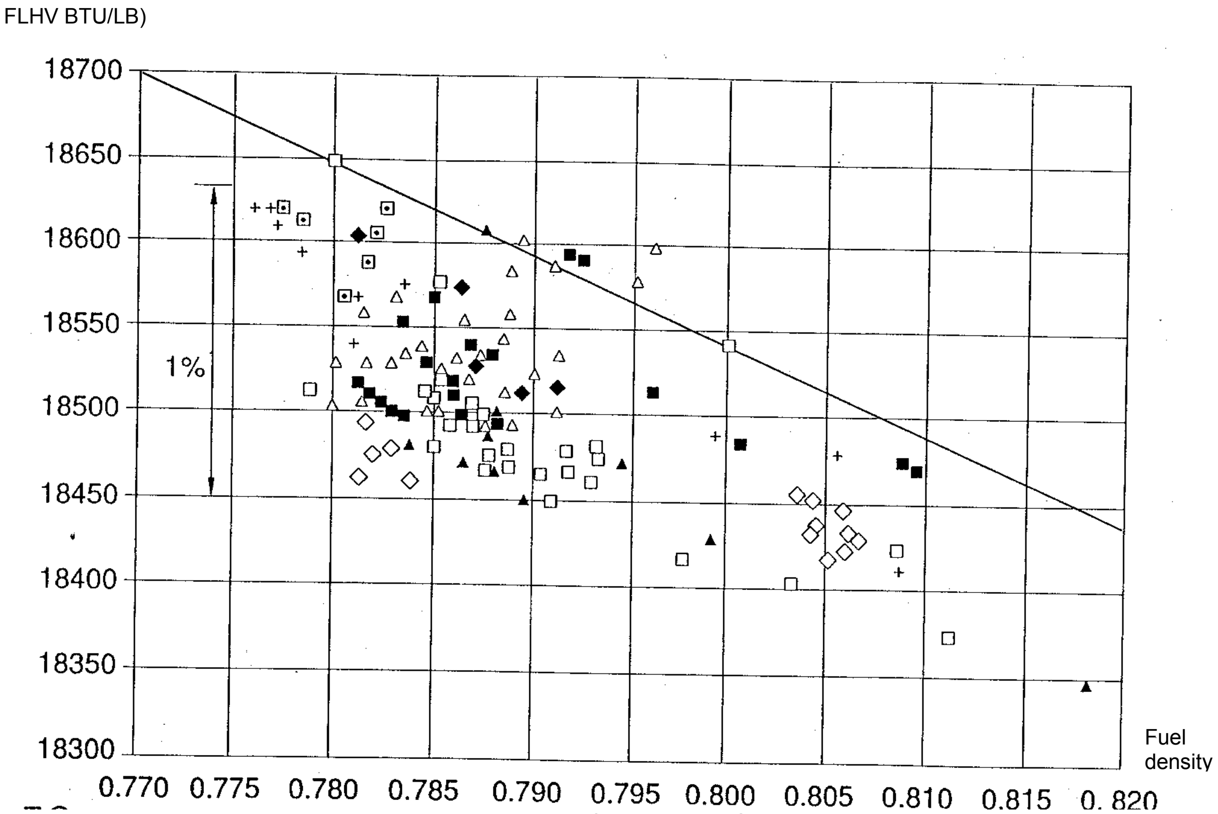


Figure B17 - FLHV values versus fuel density - Sample measurements

Figure B17 shows that the minimum fuel LHV encountered over a significant population of samples is 18400 BTU/LB.

In routine performance analysis, this FLHV is rather difficult to obtain, because of the wide variety of fuel quality, depending on various world regions. Most of the airlines subsequently use the same value for all their analysis. Although this method is rather questionable if an accurate performance audit is intended, it is quite acceptable for routine analysis.

In this case, one should keep in mind the FLHV effect on the monitored fuel factor, especially when implementing the fuel factors in the airline flight planning systems, or in aircraft FMS systems. The monitored fuel should be corrected for the FLHV effect (see also chapter *0-2.4.3. Monitored fuel factor & 0-3.2.Keys for defining the fuel factor*).

3.4.3.2. Data acquisition / transmission (Scatter/Bias)

Before data is automatically collected by means of the various aircraft recording systems, some conditions are checked. In particular, the variation of a few parameters over a 100-second time period allows to identify cruise stabilized segments. More details are available in chapter *D- How to record in-flight parameters.*

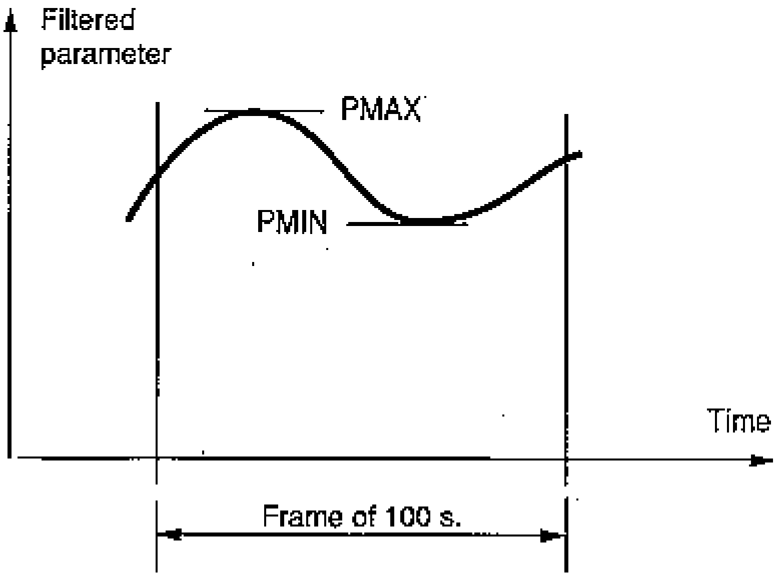


Figure B18: Stable frame = PMAX-PMIN < DP limit for all parameters

The FDIMU/DMU collects most of the data. The data comes from the various aircraft systems (such as the ADIRS, the FAC…). Potential accuracy tolerance remains in the normal industrial tolerances for each of these systems.

Some of the data is measured by the systems, and therefore can suffer from measurement error. Some other data (such as the flight path acceleration parameter, which quantifies the change of aircraft speed along the flight path) are calculated by means of the FDIMU/DMU based on an average of several other parameters. As a consequence, a rounding error comes on top of the measurement and tolerance errors.

Yet, the total error on the overall data collection remains quite low when compared to the other potential sources of errors described in this chapter.

On the data transmission side (either via ACARS, or dumping on a PCMCIA or disk), the only errors possible are due to a FDIMU/DMU malfunction.

3.4.4. Taking into account influence factors

When doing an aircraft performance audit, it is important to deal with all these bias / scatter effects in the best way possible. The following measurement considerations/corrections factors are essential:

Introducing bias	Introducing scatter
Fuel LHV	data acquisition/transmission
Aircraft weight	instrument scatter
air conditioning / bleed selection options	Auto-throttle / autopilot activity
aircraft trimming	atmospheric influences
instrument accuracy	stabilizer / elevator / trim

When doing routine aircraft performance monitoring, it is difficult to try assessing the impact of the previously mentioned factors. Indeed, taking a fuel sample to the laboratory for each flight is really not feasible. Hence, some assumptions must be made, leading to introduce some uncertainty on the cruise performance analysis. Routine aircraft performance monitoring is based on a statistical approach, which gives an average deterioration and the associated scatter.

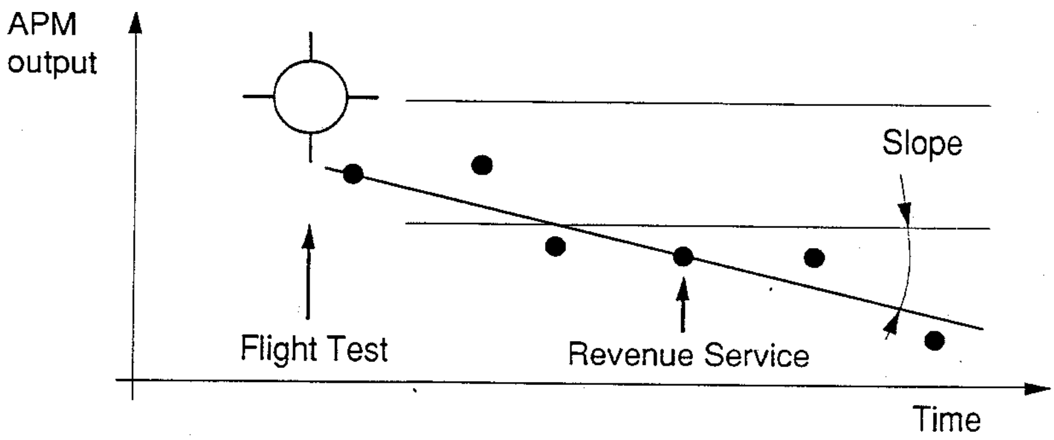


Figure B19: Performance monitoring trends

Identifying trends is rather the goal of routine performance monitoring. Figure B20 illustrates the type of trending that can be performed with the APM program.

```
* A I R B U S   C R U I S E   P E R F O R M A N C E  *  A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G *
*  ========================================================================================================================  *
*                                 ***  PROGRAM:  A P M  - Version 2.43 - Jul. 2002  ***                                      *
*                                                                                                                            *
*  ------  AIRCRAFT TYPE:      A319-114                 ENGINE TYPE:     CFM56-5A5            -----------------------------  *
*                                                                                                                            *
*  ------  DATABASES:  AERODYN. :  A319113.BDC                                                     DATE: 27/07/00     ------ *
*          ----------  ENGINE   :  M565A5.BDC                                                      DATE: 06/06/96     ------ *
*                      GENERAL  :  G319113.BDC                                                     DATE: 26/02/01     ------ *
*                                                                                                                            *
*  ------  JOB-INFORMATION:                                                                 -----------------------------   *
******************************************************************************************************************************
                                          DIRECT ANALYSIS OUTPUT (INPUT BY ADIF)
```

DATA BLOCK/FLEET: 1/ 1

F L I G H T   D A T A

CASE IDENTIFICATION

NO.	TAIL-NO	DATE D/M/Y	FL-NO	CASE (UTC)	ESN1	ESN2	ALT FEET	MACH -	TAT C	WEIGHT LB	CG %	FPAC G	VV FT/MIN	GRAV M/S*S
1	AIB001	25/05/02	202	22:55	733266	733267	37011.	0.8015	-32.55	119400.	23.7	0.0005	6.0	9.7319
2	AIB001	24/05/02	471	11:59	733266	733267	39003.	0.7700	-38.30	122300.	25.2	-0.0011	3.0	9.7703
3	AIB001	07/06/02	850	11:54	733266	733267	37017.	0.7990	-21.85	123500.	25.7	0.0001	0.0	9.7330
4	AIB001	29/05/02	1019	13:27	733266	733267	39006.	0.8000	-35.75	119000.	24.2	0.0006	0.0	9.7817
5	AIB001	04/06/02	1019	18:16	733266	733267	38988.	0.7765	-21.95	122250.	24.9	0.0012	-5.0	9.7833
6	AIB001	28/05/02	1020	21:38	733266	733267	37010.	0.7805	-34.45	128450.	24.4	0.0013	11.0	9.7483
7	AIB001	10/06/02	1023	23:21	733266	733267	37004.	0.8000	-19.65	130000.	23.9	0.0001	3.0	9.7535
8	AIB001	10/06/02	1515	11:04	733266	733267	39001.	0.7995	-27.75	114000.	24.7	-0.0001	3.5	9.7690
9	AIB001	27/05/02	1550	21:38	733266	733267	37024.	0.7990	-30.95	126200.	25.7	0.0001	-22.0	9.7426
10	AIB001	03/06/02	1550	21:48	733266	733267	37028.	0.8005	-30.05	127900.	25.1	0.0009	-22.0	9.7442
11	AIB001	19/05/02	1628	19:51	733266	733267	37003.	0.7990	-33.85	120700.	26.3	0.0004	-1.0	9.7435
12	AIB001	24/05/02	1835	20:05	733266	733267	35012.	0.8015	-24.75	134050.	24.1	0.0009	4.5	9.7803


```
* A I R B U S   C R U I S E   P E R F O R M A N C E  *  A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G *
*  ========================================================================================================================  *
*                                 ***  PROGRAM:  A P M  - Version 2.43 - Jul. 2002  ***                                      *
*                                                                                                                            *
*  ------  AIRCRAFT TYPE:      A319-114                 ENGINE TYPE:     CFM56-5A5            -----------------------------  *
*                                                                                                                            *
*  ------  DATABASES:  AERODYN. :  A319113.BDC                                                     DATE: 27/07/00     ------ *
*          ----------  ENGINE   :  M565A5.BDC                                                      DATE: 06/06/96     ------ *
*                      GENERAL  :  G319113.BDC                                                     DATE: 26/02/01     ------ *
*                                                                                                                            *
*  ------  JOB-INFORMATION:                                                                 -----------------------------   *
******************************************************************************************************************************
```


AIRCRAFT TAIL-NO.: AIB001 DIRECT ANALYSIS OUTPUT (INPUT BY ADIF) DATA BLOCK/FLEET: 1/ 1

E N G I N E   D A T A

NO.	N11 %	N12 %	FFA1 LB/H	FFA2 LB/H	EGT1 C	EGT2 C	BC	WBLL LB/S	WBLR LB/S	FLHV BTU/LB	N1TH %	FFTH LB/H	FFC1 LB/H	FFC2 LB/H	EGTC1 C	EGTC2 C
1	86.60	85.70	2410.0	2440.0	584.0	581.0		0.960	0.960	18590.	86.05	2405.5	2468.3	2364.0	577.5	564.4
2	85.80	85.80	2180.0	2180.0	576.0	576.0		0.930	0.930	18590.	85.41	2139.1	2179.2	2179.2	563.2	563.2
3	88.40	88.20	2500.0	2530.0	626.0	624.0		0.960	0.960	18590.	87.99	2481.7	2530.8	2507.1	613.5	610.4
4	87.00	87.00	2340.0	2370.0	596.2	603.0		0.930	0.860	18590.	86.81	2306.7	2327.7	2324.8	582.0	581.0
5	89.20	88.90	2420.0	2430.0	647.0	646.0		0.930	0.930	18590.	89.16	2348.2	2352.1	2320.3	627.4	622.9
6	86.50	86.20	2440.0	2440.0	585.6	590.6		0.930	0.940	18590.	86.11	2394.2	2437.7	2404.8	574.7	570.5
7	89.60	89.50	2630.0	2670.0	648.8	648.4		0.960	0.960	18590.	89.19	2600.1	2648.9	2637.0	633.6	632.1
8	87.00	86.90	2280.0	2280.0	608.0	609.0		0.930	0.930	18590.	87.32	2264.9	2231.2	2220.6	588.8	587.4
9	86.60	86.50	2460.0	2470.0	593.0	593.0		0.960	0.960	18590.	86.55	2435.2	2441.1	2429.6	578.9	577.5
10	87.30	86.90	2510.0	2520.0	604.0	601.0		0.960	0.960	18590.	87.27	2507.9	2511.4	2465.9	589.9	584.0
11	85.90	85.70	2390.0	2380.0	579.0	583.0		0.930	0.930	18590.	85.71	2378.0	2400.7	2377.2	565.9	563.0
12	87.90	87.60	2770.0	2760.0	612.2	618.6		0.960	0.960	18590.	87.69	2730.7	2756.8	2718.8	601.6	597.2

```
*  A I R B U S   C R U I S E   P E R F O R M A N C E   *   A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G  *
*  ====================================================================================================================  *
*                                  ***  PROGRAM:  A P M  - Version 2.43 - Jul. 2002  ***                                 *
*                                                                                                                        *
*  ------  AIRCRAFT TYPE:     A319-114                ENGINE TYPE:     CFM56-5A5         ----------------------------    *
*                                                                                                                        *
*  ------  DATABASES:  AERODYN. :  A319113.BDC                                                DATE: 27/07/00    ------   *
*          ----------  ENGINE   :  M565A5.BDC                                                 DATE: 06/06/96    ------   *
*                      GENERAL  :  G319113.BDC                                                DATE: 26/02/01    ------   *
*                                                                                                                        *
*  ------  JOB-INFORMATION:                                                          ----------------------------        *
**************************************************************************************************************************
AIRCRAFT TAIL-NO.:  AIB001              DIRECT ANALYSIS OUTPUT (INPUT BY ADIF)                 DATA BLOCK/FLEET:   1/ 1
```

A P M   D E V I A T I O N   D A T A

NO.	DN11	DN12	DFFA1	DFFA2	DFFB1	DFFB2	DEGT1	DEGT2	DN1M	DFFAM	DFFBM	DEGTM	DSR
	%	%	%	%	%	%	%	%	%	%	%	%	%
1	0.547	-0.353	2.612	-1.726	-2.364	3.215	0.765*	1.980	0.097	0.443	0.365	1.368	-0.803
2	0.392	0.392	1.877	1.877	0.036	0.036	1.531	1.531	0.392	1.877	0.036	1.531	-1.877
3	0.412	0.212	1.978	1.023	-1.217	0.914	1.414	1.535	0.312	1.500	-0.157	1.474	-1.323
4	0.190	0.190	0.909	0.785	0.529	1.943	1.666	2.575	0.190	0.847	1.235	2.120	-2.050
5	0.037	-0.263	0.168	-1.188	2.886	4.729*	2.174	2.573	-0.113	-0.510	3.801*	2.373	-3.168*
6	0.393	0.093	1.820	0.442	0.093	1.466	1.282	2.377	0.243	1.131	0.774	1.828	-1.878
7	0.411	0.311	1.877	1.420	-0.713	1.252	1.678	1.805	0.361	1.649	0.267	1.742	-1.884
8	-0.321*	-0.421	-1.490*	-1.956	2.187	2.674	2.223	2.510	-0.371*	-1.723*	2.430	2.366	-0.661
9	0.051	-0.049	0.241	-0.232	0.775	1.664	1.650	1.820	0.001	0.005	1.218	1.735	-1.208
10	0.031	-0.369	0.142	-1.674	-0.057	2.195	1.628	1.978	-0.169	-0.766	1.059	1.803	-0.284
11	0.194	-0.006	0.954	-0.032	-0.445	0.116	1.556	2.395	0.094	0.461	-0.166	1.975	-0.294
12	0.207	-0.093	0.955	-0.436	0.480	1.516	1.211	2.465	0.057	0.259	0.995	1.836	-1.241
MV	0.260	-0.030	1.230	-0.142	0.183	1.545	1.637	2.129	0.133	0.627	0.733	1.846	-1.228
SD	0.179	0.278	0.848	1.294	1.402	0.973	0.318	0.398	0.185	0.865	0.773	0.321	0.650
NR	11	12	11	12	12	11	11	12	11	11	11	12	11

* VALUES OUT OF RANGE (MARKED BY A TRAILING "*") ARE NOT INCLUDED IN MEAN VALUES (MV) AND STANDARD DEVIATIONS (SD).
SO NUMBER OF CASES MAY BE REDUCED TO NUMBER OF READINGS (NR). ".---" MEANS FAILED OR NOT CALCULATED.

Figure B20: Trending with the APM program

Figure B20 analysis shows that this particular tail number consumes more fuel than the IFP book level by 1.228% (worse specific range by 1.228%) in average. Based on the sample in-flight records that were snapshot during the flight, the deviation to this mean value was ±0.65%. Eleven records were used to calculate the statistics.

More details concerning data interpretation is available in *Chapter D-Cruise Performance Analysis*.

3.5. Conclusion

3.5.1. Trends and factoring

Routine aircraft performance monitoring is double-purpose. First, it enables to establish the different fuel factors for aircraft operations for each individual aircraft. Second, it allows to monitor the natural performance deterioration trend with time.

Trends can provide essential information concerning the impact of a maintenance policy provided adequate book-keeping is performed to record:

- numeric APM outputs before and after maintenance actions,
- strategic maintenance actions (airframe, engines, instruments).

Deteriorating from delivery, each individual aircraft specific range trends compared to the Airbus baseline provide the performance factor that is eventually entered into that aircraft's FMS and in the flight planning system for fuel padding.

To illustrate the trend of the aircraft performance deterioration with time, and based on the feedback from A320 family customers, the following typical in-service performance values in terms of specific range versus the corresponding IFP level are as follows:

- after 1 year from delivery: 2.0% below IFP +/- 1%
- after 2 years from delivery: 3.5% below IFP +/- 1%
- after 3 years from delivery: 4.0% below IFP +/- 1%

3.5.2. Comparing performance monitoring methods

Moreover, when checking the actual performance level of an aircraft, many factors may influence the analysis by introducing bias and/or scatter. Although corrections may be calculated for each individual factor, this procedure appears to be quite hard when routine performed.

Overall, three basic methods are available to check the actual performance level of the aircraft versus the book level: the specific range method ($\frac{\Delta SR}{SR}$), the fuel used method ($\frac{\Delta FU}{FU}$), the fuel on board method ($\frac{\Delta FBO}{FBO}$). Depending on the method used, part or all of the influencing factors are taken into account. Each method gives an apparent performance level of the aircraft, which is the combination of the actual aircraft performance level and of the influencing factors.

Figure B21 illustrates how the specific range method, the fuel used method, the fuel on board method relate to each other and relative to the IFP baseline.

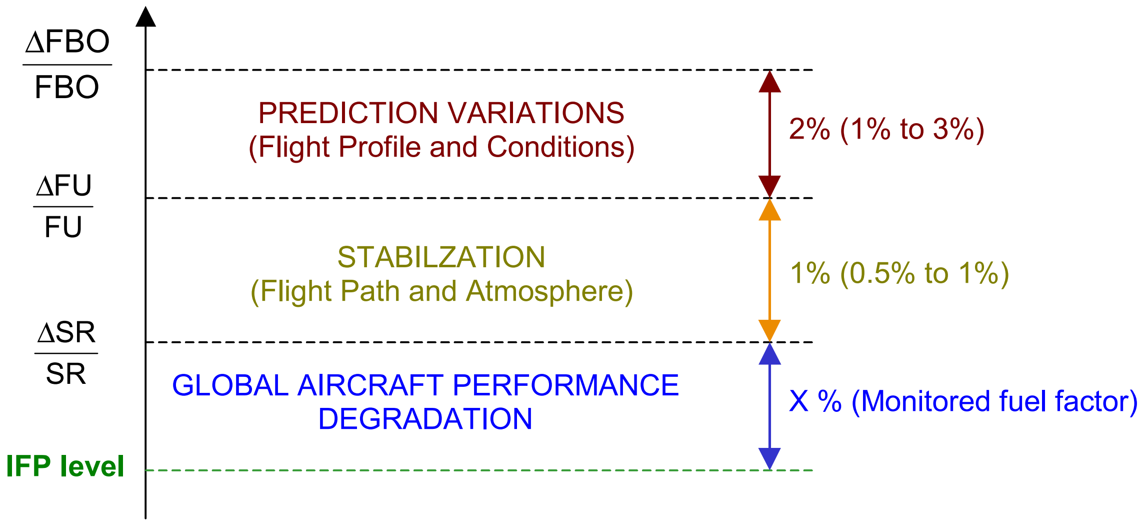


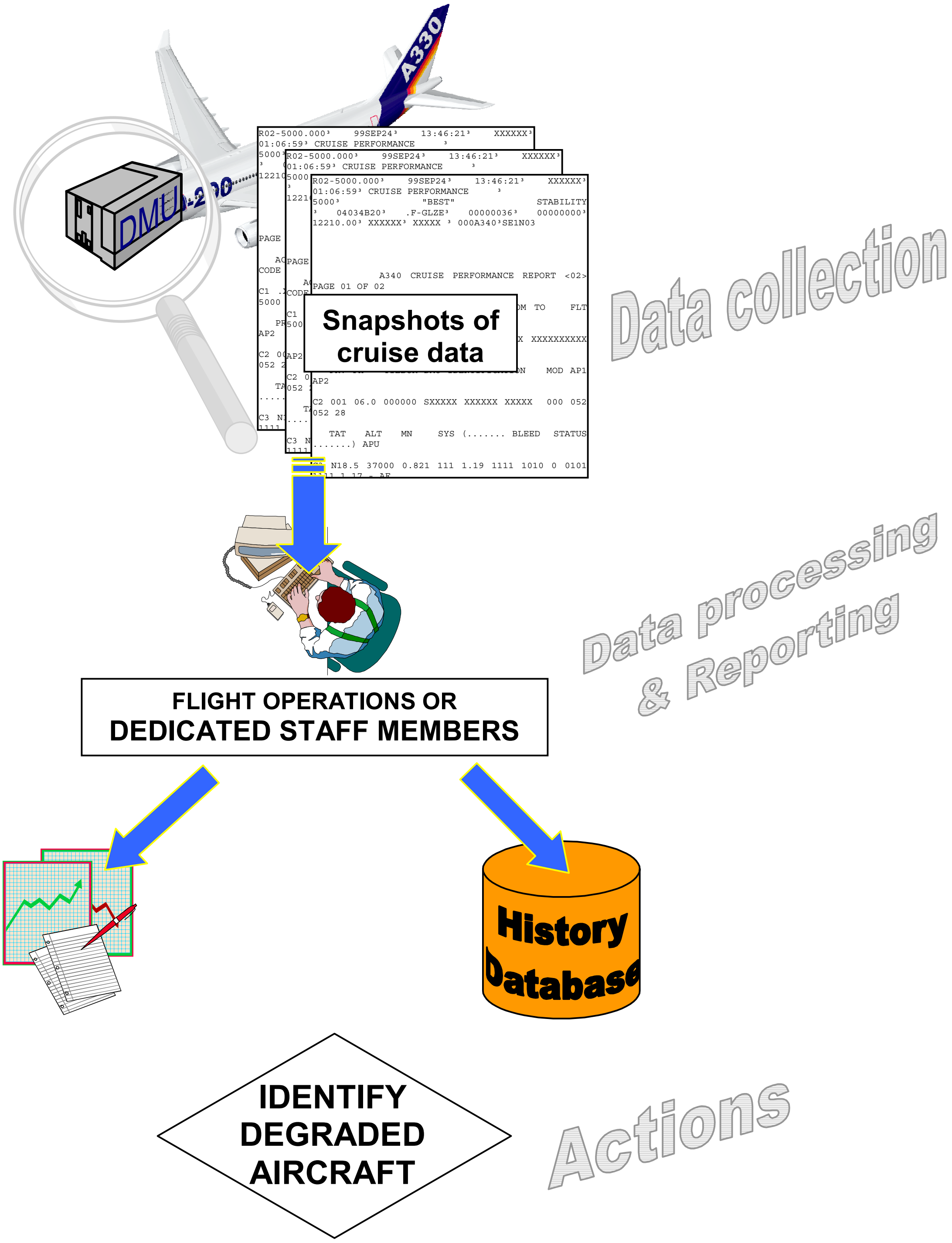
Figure B21: Performance monitoring method comparison

All the above methods naturally have relative advantages and disadvantages which airlines have to weigh out against each other.

	Advantages	Disadvanges	Comments
Specific range method	Potential splitting of engine and airframe Easy processing	Scatter, sensitive Stability critical	Not adapted for factoring on short/medium-haul
Fuel-used Method	Easy data gathering Scatter elimination ATS remaining in use	No bias elimination Tedious processing	Adapted for flight planning Operational conditions
Trip fuel burn-off analysis	Scatter elimination ATS remaining in use	More crew attention required Tedious data gathering and processing	Adapted for fuel factoring on short-haul.

4. AIRCRAFT PERFORMANCE MONITORING COMMUNITY

Aircraft Performance Monitoring involves many actors within the airline. On the next page, a sample data flow was drawn for a typical airline. Of course, the organization of the airline may impose different data flows but this aims at giving an overall idea of the task sharing when dealing with aircraft performance monitoring.



MANAGEMENT		
MAINTENANCE ENGINEERING - Monitoring of the engine performance - Repair airframe non-clean surfaces (flight control rigging, seals, …) - Calibration of airspeed system and static sources - Control of the OEW	**FLIGHT OPERATIONS** - Flight planning - Route restrictions	**AIRFRAME AND POWER ENGINEERING** - Long term engine condition monitoring - Assess the effectiveness of maintenance procedures and airframe modifications

LEFT INTENTIONALLY BLANK

C. HOW TO RECORD IN-FLIGHT PARAMETERS

This chapter introduces to the Airbus' methodology for fuel mileage determination in terms of monitoring procedures and data retrieval.

1. INTRODUCTION

Data retrieval is the key point to aircraft performance monitoring. The quality and the quantity of records will govern the reliability of performance monitoring to a great extent. Two procedures for data retrieval from the aircraft will be detailed:

1. Manual recording of in-flight data based on data monitoring of the cruise performance.
2. Automatic recording of in-flight data based on the use of data recorders on board the aircraft.

These procedures have been developed to monitor cruise performance during stable flight conditions.

For all aircraft types, data collection can be performed manually by means of a dedicated staff member in the cockpit or by one of the pilots. It is worth noticing that the manual data collection quickly becomes tedious when the aircraft performance level is monitored systematically and repetitively.

That is why Airbus promotes the automatic data collection (whenever possible) for routine aircraft performance monitoring. Airbus worked this out and defined a standard report format produced by aircraft systems and a tool for analysis that is able to cope with the report without any further handling operations.

Note that both procedures should give the same results and that the choice of the method remains at the user's discretion. Both methods are not exclusive and can be performed simultaneously and independently from each other to increase reliability of data readings.

2. REQUIRED OBSERVED DATA

The data that is required for further analysis is given below. Each observed data set is like a snapshot of aircraft condition. As many records as possible should be obtained so as to increase the statistical adequacy of performance analysis.

Parameter	Unit	Comments
Aircraft Tail Number	(–)	
Date	YYMMDD	
Flight Number	(–)	
Flight Case or DMU recording time	1-99	Number of data of a same flight. If no value is set, the program sets a "1".
	hhmm	Time at which the performance point was taken in flight.
Engine serial numbers	(–)	
Altitude	(ft)	From the two air data computers (ADC)
Mach number	(–)	From the two air data computers (ADC)
Total Air Temperature	(°C)	From the two air data computers (ADC)
Aircraft mass (weight)	(kg or lb)	
Center of Gravity	(%)	
Flight Path Acceleration	(g)	Horizontal acceleration measured in g.
Vertical Velocity	(ft/min)	Vertical acceleration
True Heading	(°)	Optional - used only if gravity correction activated.
Latitude	(°)	Optional - used only if gravity correction activated.
Wind speed	(kt)	Optional - used only if gravity correction activated.
Wind direction	(°)	Optional - used only if gravity correction activated
Average fuel temperature	(°C)	NOT ACTIVE
Average fuel density	(l/kg)	NOT ACTIVE
N1 - Power setting EPR - Power Setting	(%) (–)	Depends on engine type EPR for IAE, RR and P&W engines, N1 for GE and CFM engines.
Actual fuel flow	(kg/h, lb/h)	Fuel flow for each engine (FFA1, FFA2, ...)
Exhaust gas temperature	(°C)	To be set for each engine (EGT1, EGT2, ...)
Fuel lower heating value	(BTU/lb)	
Engine bleed flow (left)	(kg/s or lb/s)	Engine 1 flow (twin engine A/C) or sum of engines 1 and 2 (4 engine-aircraft)
Engine bleed flow (right)	(kg/s or lb/s)	Engine 2 flow (twin engine A/C) or sum of engines 3 and 4 (4 engine-aircraft)
Engine bleed code (alternatively to pack flows)	(–)	0 ... off (no bleed) E ... economic (low) N ... normal H ... high (max)

3. MANUAL RECORDING

Manual readings have to be performed when the aircraft is not equipped with the appropriate equipment required for automated data retrieval. The required material is detailed in the next paragraph.

Doing manual readings requires to comply with strict rules to avoid irrelevant points. Some highlights will also be given concerning analysis procedures and the use of recording systems.

3.1. Measurement procedures and precautions

A performance monitoring must be carried out considering all the following measurement procedures and precautions.

These recommendations have been summarized in the form given at the end of this paragraph.

3.1.1. At dispatch

- Take a copy of the computerized flight plan, the weather forecast and of the load sheet.

- Take a fuel sample from the refueling truck for analysis and determination of the fuel LHV. The FLHV of the sample can be determined by specialized laboratories.

- Check the external aspect of the aircraft to detect any seal degradation, any flight control surface and door misrigging, any airframe repair, the airframe surface condition, which all could increase the aircraft drag. Take pictures and annotate aircraft schematics to detail observations.

- Note aircraft tail number, date and flight sector.

3.1.2. Prior to take off

- Record the fuel on board (FOB) at Main Engine Start (MES), either by the on-board fuel quantity indication (FQI).

- Note Zero Fuel Weight (ZFW) from the load sheet.

- Calculate aircraft gross weight at MES (read it on the ECAM).

- Note APU running time after MES and compute APU fuel consumption to amend engine fuel used (100 / 150 kg / hour).

- Note the take off Center of Gravity

3.1.3. In flight

- Check the aircraft is flying in cruise on a straight leg that will take at least 15 minutes.

- Perform fuel balancing if unbalance between wing tanks exists. Check fuel unbalance is not due to a fuel leak.

- Disconnect autothrust and set N1/EPR at an appropriate value to maintain a constant speed

- Do not touch the thrust levers during the whole subsequent period unless recordings are stopped because of instability.

- Engage autopilot in ALT HLD/HDG SEL mode.

- Select air conditioning flow normal, both bleeds packs ON, engine anti-ice OFF, wing anti-ice OFF.

- Wait for 5 minutes for aircraft stabilization before starting the data recording (take EGT, ground speed and SAT as references).

- Check the initial drift angle is less than 5 degrees and that the rate of change does not exceed 0.5 degree per minute.

- Start the recording process after stability criteria are achieved (refer to paragraph *3.1.4. Data Recording*).

<u>*Notes*</u>

1. *When flying on a long-range flight, it is recommended to collect data at different gross weight/altitude combinations whenever possible (high gross weight/low altitude at the beginning of a flight, low gross weight/high altitude at the end of a flight).*
2. *A visual inspection of spoilers, ailerons, slats and flaps position can be conducted in cruise, to detect any possible aerodynamic disturbance which could increase aircraft apparent drag.*
3. *It is recommended not to start recording before 15 minutes after the top of climb, in order to avoid transient engine behaviors.*

3.1.4. Data Recording

Data recording will be carried out during at least 6 minutes if favorable stability conditions are maintained.

Data recordings samples will be validated considering the following stability criteria:

- Delta pressure altitude: $\Delta Zp \leq \pm 20$ ft
- Delta static air temperature: $\Delta SAT \leq \pm 1°C$
- Delta Ground Speed to delta time ratio: $\frac{\Delta GS}{\Delta t} \leq 1 kt/min$
- Delta Mach Number: $\Delta Mach \leq \pm 0.003$.
- Drift angle less than 5 degrees

The following parameters will be recorded at the rate specified in the table below:

Parameter	Note at intervals of	Parameter	Note at intervals of
- Altitude (Zp) - Mach (M) / TAS - TAT / SAT - N1 (or EPR) - CG and rudder trim	60 seconds 60 seconds 60 seconds 60 seconds 60 seconds	- Fuel flow (FF) - EGT - Fuel used (FU) - Ground speed (GS)	60 seconds 60 seconds 60 seconds 60 seconds (check every 30 seconds for variations)

In addition the approaching station will be noted, as well as the drift angle. The drift angle is a triggering condition used to assess one record.
Heading, wind velocity and direction, track will be also monitored so as to determine their respective impact due to the Coriolis effect. The latter is an optional step as the Coriolis effect is of a second order effect.

Do not forget to consult weather charts (forecasted and actual ones) to confirm actual pressure patterns.

3.2. Forms for manual reading

When collecting data manually in the cockpit, a number of data has to be written down in a short period of time so as to constitute a complete record.

The following pages show some pre-formatted forms are available to properly record the data:
- a check list of what to do before flight,
- an in-flight observation form,

CRUISE PERFORMANCE ANALYSIS - PRE-FLIGHT FORM	Page

A/C No		**Flight No**	
Date		**From**	
		To	

CHECK LIST

AT DISPATCH

- Computerized flight plan ☐
- Weather forecast ☐
- Load sheet ☐
- Fuel sample for FLHV analysis ☐
- Aircraft visual inspection ☐

BLOCK

FOB		APU START TIME	
ZFW		APU STOP TIME	
ZFCG		APU RUNNING TIME	
AIRCRAFT WEIGHT		APU FUEL CONSUMPTION	

TAKEOFF

ENGINE START TIME		TAKEOFF TIME	
TAKEOFF WEIGHT		QNH	
TAKEOFF CG		V1/VR/V2	
		RWY ID	

CRUISE

COST INDEX		PERF FACTOR	

Before any point is recorded in-flight, you have to go through the following process

Only start recording after going through the preliminary process.

- Leg of at least 15 minutes flight long ☐
- Fuel unbalance between wing tanks ☐
- Disconnect autothrust and set N1/EPR to appropriate value ☐
- Engaged autopilot in ALT HLD/HDG SEL mode. ☐
- Select AC flow normal, both bleed/pack ON, engine and wing A/I OFF ☐

Additional recommendations

Do not touch the thrust levers during the whole subsequent period unless recordings are stopped because of instability.

Wait for 5 minutes for aircraft stabilization before starting actual data recording (references are EGT, N1/EPR, ground speed and SAT).

Check the initial drift angle to be less than 2.5 degrees and rate of change not exceeding 0.5 degree per minute.

Specific checks have to be performed during flight - refer to the in-flight observation form

COMMENTS

CRUISE PERFORMANCE ANALYSIS - FLIGHT OBSERVATION FORM

A/C No ______ **Flight No** ______

START TIME ______ Page ______

Recommendations

Monitor stability of: G/S, Mn, Drift, SAT, FPAC, Wind (force and direction), balance of fuel in the tanks

Disconnect A/THR and switch to HDG mode

In-flight data

AC LO/ECON ☐ NO ☐ HI ☐

CARGO COOLING ON ☐ OFF ☐

DRIFT ANGLE ______ DEG

SAT ______ DEG

REPORT INITIAL WEIGHT ______ KG
CG ______ %
HEADING ______ DEG
LATITUDE ______ DEG

GROUND SPEED											ALT	MN	TAT	**WIND**	**N1/EPR**				**FF**				**FU/EGT**			
-5	-4	-3	-2	-1	0	1	2	3	4	5				HDG/F	1	2	3	4	1	2	3	4	1	2	3	4
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/
														/									/	/	/	/

3.3. Data analysis procedure

Based on in-flight recorded data, aircraft stability will be assessed from the ground speed. The most representative of a 6-minute run will be selected. One or more 6-minute shots will be retained if possible. Stability criteria given in the previous paragraph will also guide this choice.

The input data must be prepared for and analysis according to the following rules:
- Pressure altitude, Mach number, TAT, N1 (or EPR) and fuel flow will be averaged over the selected 6 minute-portion.
- Aircraft gross weight will be based on the difference between ramp weight at MES and fuel used at center point of the selected 6 minute-portion.
- The aircraft CG will be calculated from takeoff CG and fuel schedule (when not part of the recorded data)
- Aircraft acceleration along the flight path (FPAC) will be the slope (linear regression) of ground speed over the 3-minutes frames ; the same applies for the vertical speed but sloped through altitude.

FLHV, latitude, heading are introduced to take into account fuel calorific content and Coriolis / Centrifugal and local gravity effects respectively as discussed in chapter B.

The selection of 6 minute-portions from the recorded data enables to obtain a mean value, to evaluate scatter, which is indicative of measurement stability. Final assessment is only possible when taking into account correction factors, which, in turn, also allow to decrease bias and scatter. In particular, the application of the FPAC correction effectively reduces scatter. An uncorrected FPAC of 1kt/minute corresponds to a drag deviation of approximately 1.3%.

Then, for each 6-minute segment, one set of data is obtained. The analysis of the resulting points can be performed with an Airbus specific tool, based on the specific range method: the APM program.

Statistical elimination can be selected before the analysis in the APM program. For each parameter (fuel flow, N1/EPR,…), the mean value and the standard deviation is calculated over all the records. The user can filter these records so as to get rid of lesser quality readings.
Two filters are implemented in the APM program:
- standard elimination which discards the points which are outside a 95%-confidence interval
- pre-elimination window which allows the user to eliminate the parameters which are outside a user's defined window, which is centered around the mean value.

4. AUTOMATIC RECORDINGS

4.1. What is automatic recording?

Manual recording was introduced in paragraph *3*. It is obvious that this way of collecting data cannot apply in case of routine aircraft performance monitoring.

At Airbus we have conceived a process, that minimizes handling operations. This process is based on the utilization of the aircraft recording systems for data collection. Automatic recording means configuring aircraft systems so as to get in-flight data automatically recorded for further analysis by the IFP or APM program.

To accomplish this, some specific systems are required to get the data at the relevant format. The next paragraph will give a basic comprehension of the aircraft recording systems. Note that the description depends on the aircraft type.

4.2. A300/A310/A300-600 aircraft

The aircraft data recording system includes an expanded Aircraft Integrated Data System. The AIDS allows condition and performance monitoring and/or specific engineering investigations by the operators.
An additional optional Data Management Unit (DMU) can also be installed. On the A300/A310/A300-600 aircraft types, all equipment is Buyer Furnished Equipment (BFE).

Airbus is not responsible for the AIDS/ACMS features: architecture, functions, ground requirements. As a consequence, no specification defining standard reports is available. This means that the format of the produced data is not known in advance. Saying there are as many formats as operators would be a little bit of a caricature but not that much.

Therefore, no automatic data collection for fully automated aircraft performance monitoring purpose is available for A300/A310/A300-600 aircraft types.
On the operator's side, the alternatives are:
- To manually observe the cruise phases. In that case, some constraining stability criteria must be taken into account,
- To build an in-house tool to be able to convert the material produced by the aircraft DMU into an appropriate format (provided all required data is available).

4.3. A320 family/A330/A340 aircraft

4.3.1. Introduction

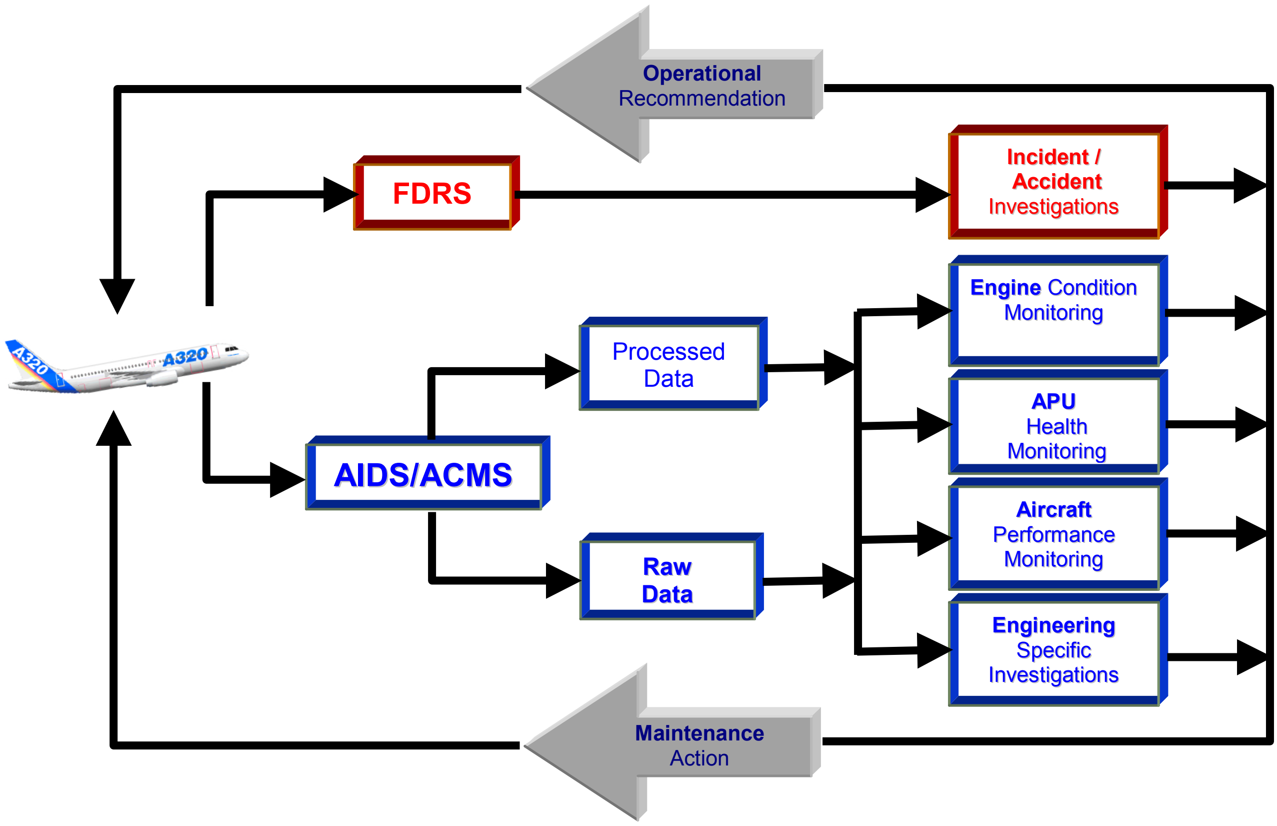
The analysis requires many parameters for one record or in-flight data set. Each in-flight data set is like a snapshot of the aircraft conditions. As many records as possible should be obtained to increase the reliability of the statistical results.

This chapter will provide an overview of the various aircraft recording systems and the way to retrieve the information.

The Aircraft Recording and Monitoring Systems are basically divided into three categories:

1. The Centralized Fault Display System (CFDS)
2. The Flight Data Recording System (FDRS)
3. The Aircraft Integrated Data System (AIDS) for the A320 family aircraft or the Aircraft Condition Monitoring System (ACMS) for A330/A340 aircraft

The FDRS and AIDS/ACMS systems are devoted to collecting some aircraft parameters. The following diagram sums up the functions of both systems. In both cases, the feedback from the aircraft allows the operators to take the appropriate actions.



Only the AIDS/ACMS system is described in the following as it is the appropriate system to collect data for automatic processing thanks to the APM program.

4.3.2. Aircraft Integrated Data System (A320 Family AIDS) / Aircraft Condition Monitoring System (A330/A340 ACMS)

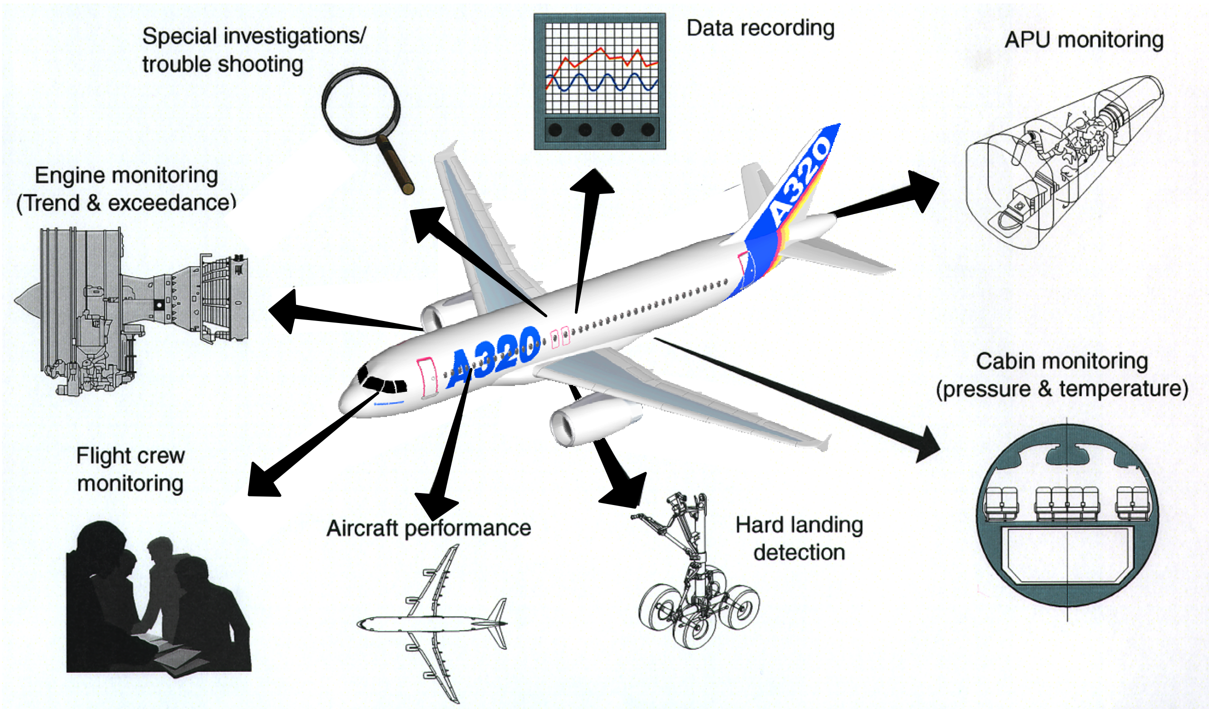
With the integration of modern state-of-the-art technology like the fly-by-wire and the Full Authorized Digital Engine Control (FADEC), the complexity of the aircraft systems led to the development of the Aircraft Integrated Data System.
While the FDRS is intended to assist operators in case of incidents/accidents, the main objectives of the AIDS/ACMS are more of a preventive nature

Long term trend monitoring of the aircraft performance really takes place in the frame of maintenance actions and is complementary to all other monitoring actions on the engines or the APU.

4.3.2.1. The AIDS/ACMS functions

AIDS/ACMS is used to monitor the aircraft systems mainly the engines, the APU and the aircraft performance in order to perform preventive action. As a consequence, it will enable operational recommendations to be formulated.

The AIDS/ACMS main functions are described in the picture below.

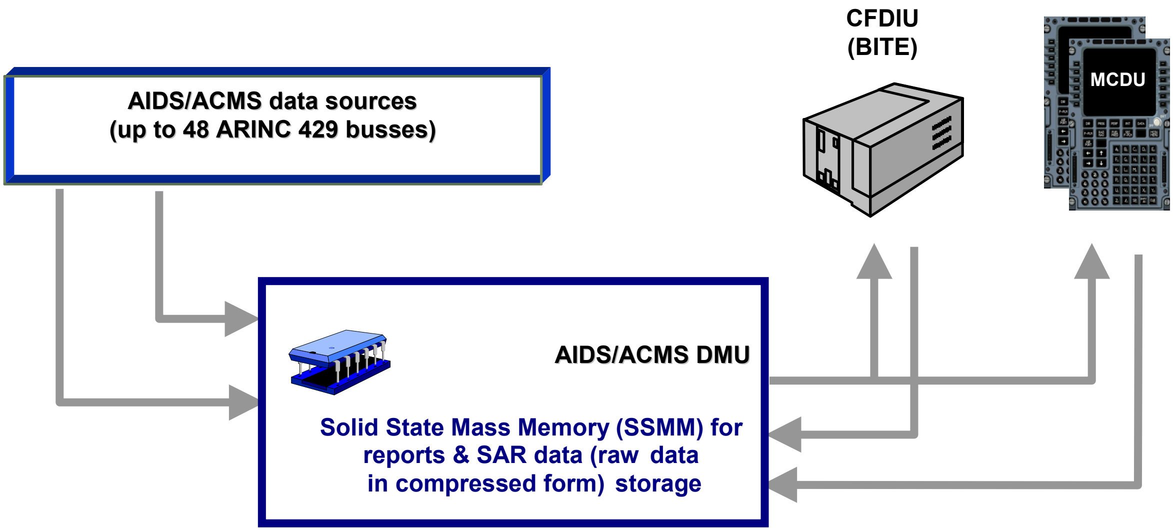


4.3.2.2. How AIDS/ACMS is implemented

The AIDS/ACMS is mainly interfaced with the Data Management Unit (DMU) or Flight Data Interface and Management Unit (FDIMU). Depending on the aircraft configuration, DMU or FDIMU may be fitted on the aircraft.

Basically, the FDIMU is a hardware combining the DMU and FDIU. Only the data management part of the FDIMU will be considered in the following.

The DMU/FDIMU is a high-performance avionics computer specialized for the acquisition of ARINC 429 Digital Information Transfer System (DITS) data and associated processing. All tasks are performed in real time. The DMU/FDIMU is the central part of the AIDS/ACMS and may be reconfigured via the Ground Support Equipment tools of the operator.
The DMU/FDIMU interfaces with other aircraft systems such as the FAC or the ADIRU. Approximatively 13000 parameters are fed into the DMU/FDIMU.



4.3.3. Generic functions of the DMU/FDIMU

Based on these parameters, the DMU/FDIMU performs several tasks:
- It processes incoming data to determine stable frame conditions, and to monitor limit exceedances,
- It generates reports according to specific programmed trigger conditions.
- Associated with a ground tool, the DMU/FDIMU is very flexible as it can be re-programmed by the operator.

4.3.3.1. The Airbus standard reports

One of the generic functions of the DMU/FDIMU is the generation of aircraft & engine reports as a result of specific events defined by triggering conditions.
The Airbus Standard Reports are a set of pre-programmed AIDS/ACMS reports, which are operative at delivery of the DMU/FDIMU.
These reports have been defined and validated by Airbus. They depend on the aircraft type (A320 family or A330 or A340) and on the engine type.

Here are all the reports available:

For Aircraft Performing Monitoring
- Aircraft Cruise Performance Report (02)

For Engine Trend Monitoring
- Engine Take-Off Report (04)
- Engine Cruise Report (01)
- Engine Divergence Report (09)

For Engine Exceedance Monitoring
- Engine Start Report (10)
- Engine Gas Path Advisory Report (06)
- Engine Mechanical Advisory Report (07)

For Engine Trouble Shooting
- Engine Run up Report (11)
- Engine On Request Report (05)

For APU Monitoring
- APU Main Engine Start/APU idle Report (13)
- APU Shutdown Report (14)

For Miscellaneous Monitoring Functions
- Hard Landing/Structural Load Report (15)
- Environmental Control System Report (19)

Report (01), (02), (04), (10) and (13) are designed for long term trend analysis.
Report (05) and (11) are designed to collect important engine data used by line maintenance for engine troubleshooting at run-up or during flight.

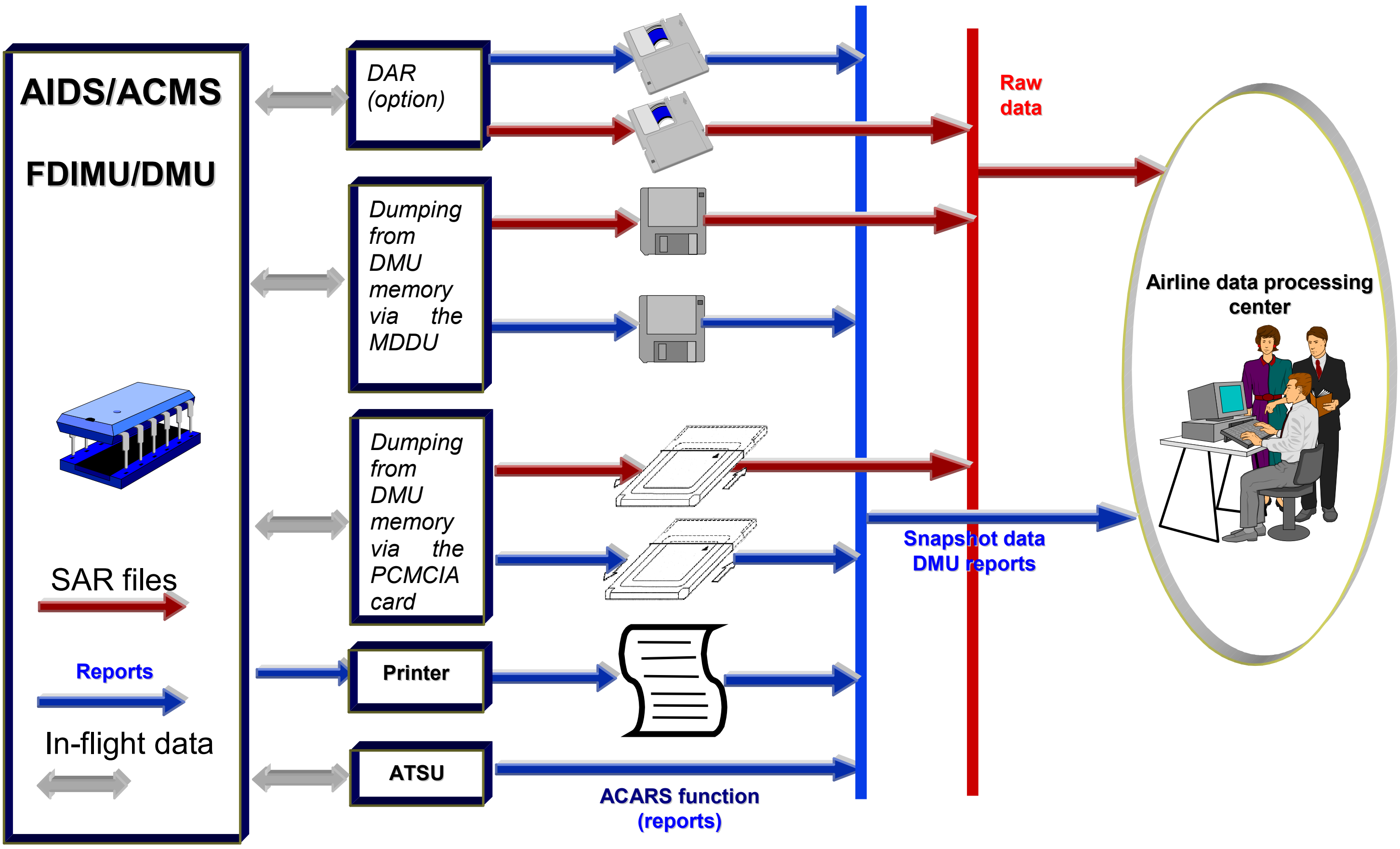
When reports (06), (07), (09), (14), (15) or (19) are automatically triggered, maintenance and investigative actions are required.

Most of these reports allow a change in the trigger limits or in the length of the report. In addition, user specific trigger conditions can be created for each report using the Ground Support Equipment tool (see below).

The reports are described in the relevant Aircraft Maintenance Manual, section 31-36-00 or in the Technical Description Note provided at the aircraft delivery by the DMU/FDIMU system manufacturer.

4.3.3.2. DMU/FDIMU transfer file interfaces

The DMU/FDIMU provides various communication interfaces for operator dialogue and ground communications. The usage of these communication channels is mostly programmable. For instance, reports can be printed out or, transmitted to the ground via ACARS or retrieved on a floppy disk via the airborne data loader (MDDU).
This means that each operator can set up the DMU/FDIMU to most efficiently support the airline specific data link structure.
The picture below shows different data flows from the aircraft to ground operations. All interfaces are then described one by one.



The DMU/FDIMU interface is composed of several devices.

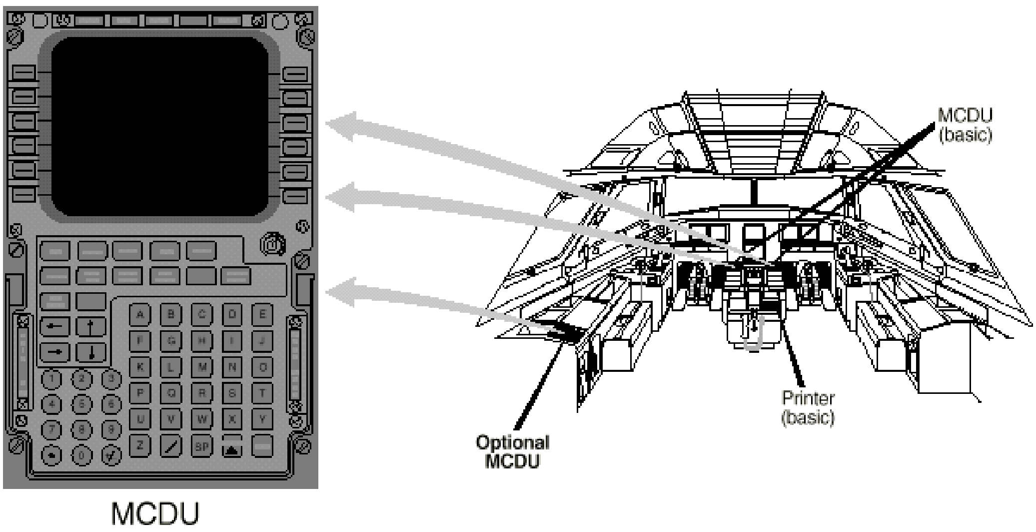
- **a Multi purpose Control and Display Unit (MCDU)**

The aim of the Multi purpose Control and Display Unit is to display and print real time AIDS/ACMS data (documentary data, status of various reports and recordings).

The MCDU also provides:
- manual triggering of reports and recordings,
- distribution of reports to multiple output devices,
- temporary reprogramming of some DMU/FDIMU parameters,
- report inhibition,
- control of the DAR/SAR.

The operator has the ability to display any digital data on the aircraft that is available to the DMU/FDIMU via the MCDU.

MCDU location



- **the cockpit printer, featuring the following functions:**

- manually initiated (via the MCDU) print out of reports
- automatic print out of reports
- print out of MCDU screens

- **an MDDU (airborne data loader), featuring the following functions:**

- manually initiated (via the MCDU) retrieval of reports
- automatic retrieval of reports
- load of DMU/FDIMU software

- **an optional Digital AIDS/ACMS Recorder (DAR)**

The DMU/FDIMU data can also be stored on an optional recorder: the Digital AIDS Recorder (DAR). It is a magnetic tape cartridge or an optical disk. This is only available for aircraft equipped with Teledyne DMU/FDIMU. The retrieval of data can be:

- manually initiated (via the MCDU) recording of reports
- automatic

- **a Smart Access Recorder (SAR)**

An integral part of the DMU/FDIMU is the optional Smart Access Recorder (SAR). It is used to store flight data. Sophisticated data compression algorithms ensure an efficient usage of the limited DMU/FDIMU memory (Solid State Mass Memory, SSMM). To read out the SAR data, the operator can use a diskette via the MDDU or a PCMCIA card via the PCMCIA interface.
The data from the SAR storage buffer can be retrieved through the airborne data loader.
To manually initiate some specific reports, a remote print button is located on the pedestal in the cockpit. The report/SAR channel assignment of the remote print button is programmable via the Ground Support Equipment (see below).

- **An optional PCMCIA card (A320 FAM aircraft only)**

The integrated PCMCIA interface can store the AIDS/ACMS standard reports. To store data via the PCMCIA interface, a PCMCIA card in MS-DOS format is required.
The advantage of the PCMCIA card is that the time to access the media is much lower than when using a floppy disk in the airborne data loader.
The PCMCIA card can be connected to a Personal Computer to dump the data for further analysis.

- **An optional ATSU (ACARS function).**

For those aircraft equipped with the Aircraft Communication and Reporting System, it is possible to send the AIDS/ACMS reports directly on the ground. The format of the reports is different from the ones that can be retrieved directly from the DMU/FDIMU (see above) because every transmission costs money.

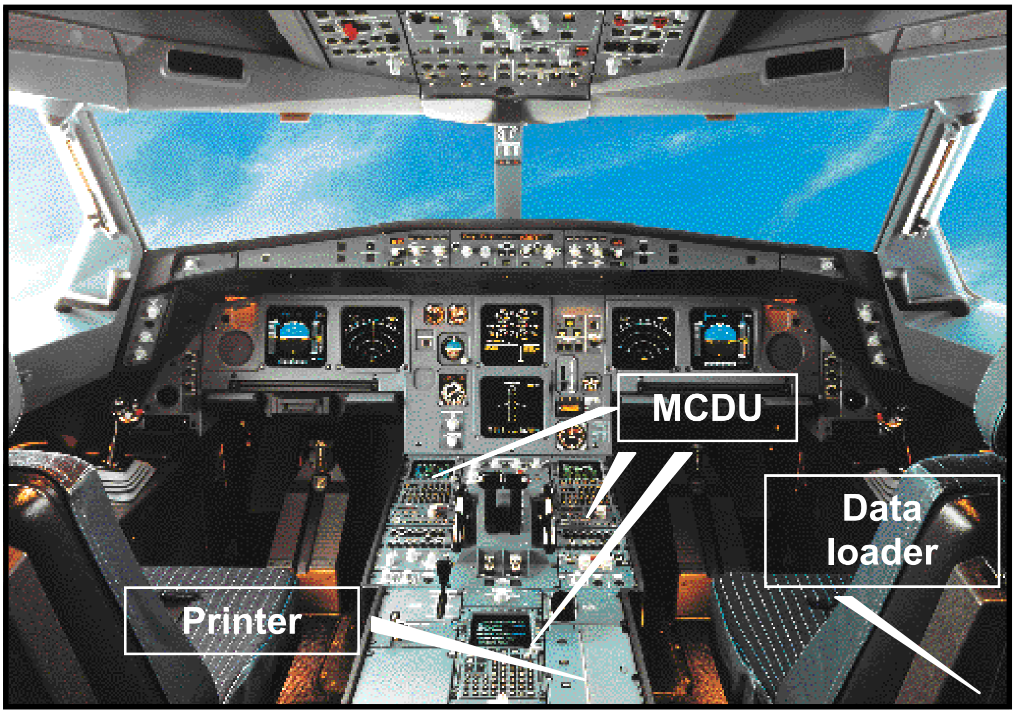
This system is essential for engine and aircraft monitoring of important fleets. It allows to transfer high quantities of data and treat these automatically.

The ACARS function / AIDS/ACMS interface provides the capability to transmit to the ground reports for the following applications:

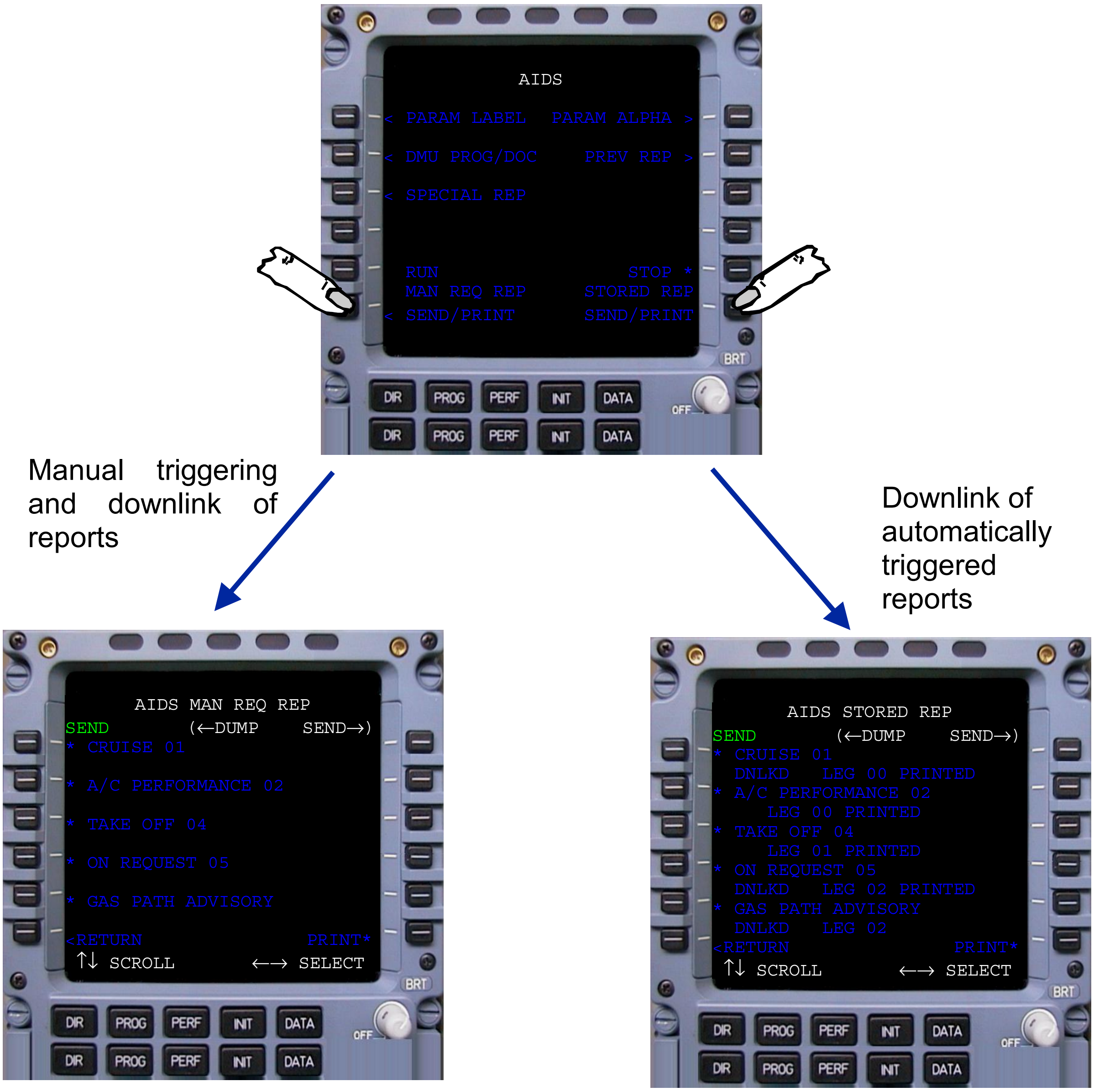
- aircraft performance monitoring : APM
- engine condition monitoring : ECM
- APU health monitoring : AHM

Any of the AIDS/ACMS DMU/FDIMU reports can be downloaded:

- manually on ground or in flight
- automatically after a particular event
- after ground request


MCDU
Data loader
Printer

4.3.3.3. Example of manual triggering downlink



4.3.3.4. Summary

The AIDS/ACMS reports can be:
- printed out on the cockpit printer in flight or on ground,
- collected by retrieving the PCMCIA card,
- downloaded on ground only from the DMU/FDIMU memory via the MDDU using a floppy disk or via the PCMCIA interface to a PCMCIA card,
- downloaded through ACARS in flight or on ground.

4.3.4. The Ground Support Equipment (GSE)

For the individual programming of the DMU/FDIMU functions, the DMU/FDIMU is programmable either with the assistance of an AIDS/ACMS GSE or partially through the MCDU (very limited). The GSE is a software developed by the DMU/FDIMU manufacturer. **The GSE is under airline responsibility.**

4.3.4.1. AIDS/ACMS reconfiguration tool

The tool can be used:
- to program trigger conditions, processing algorithms, layout of report formats, and the DAR & SAR recording format.
- to configure the AIDS/ACMS DMU/FDIMU database
- to create user programmable reports, sophisticated aircraft monitoring and data collection functions.

The program is loaded into the DMU/FDIMU on ground using the MDDU or the PCMCIA card

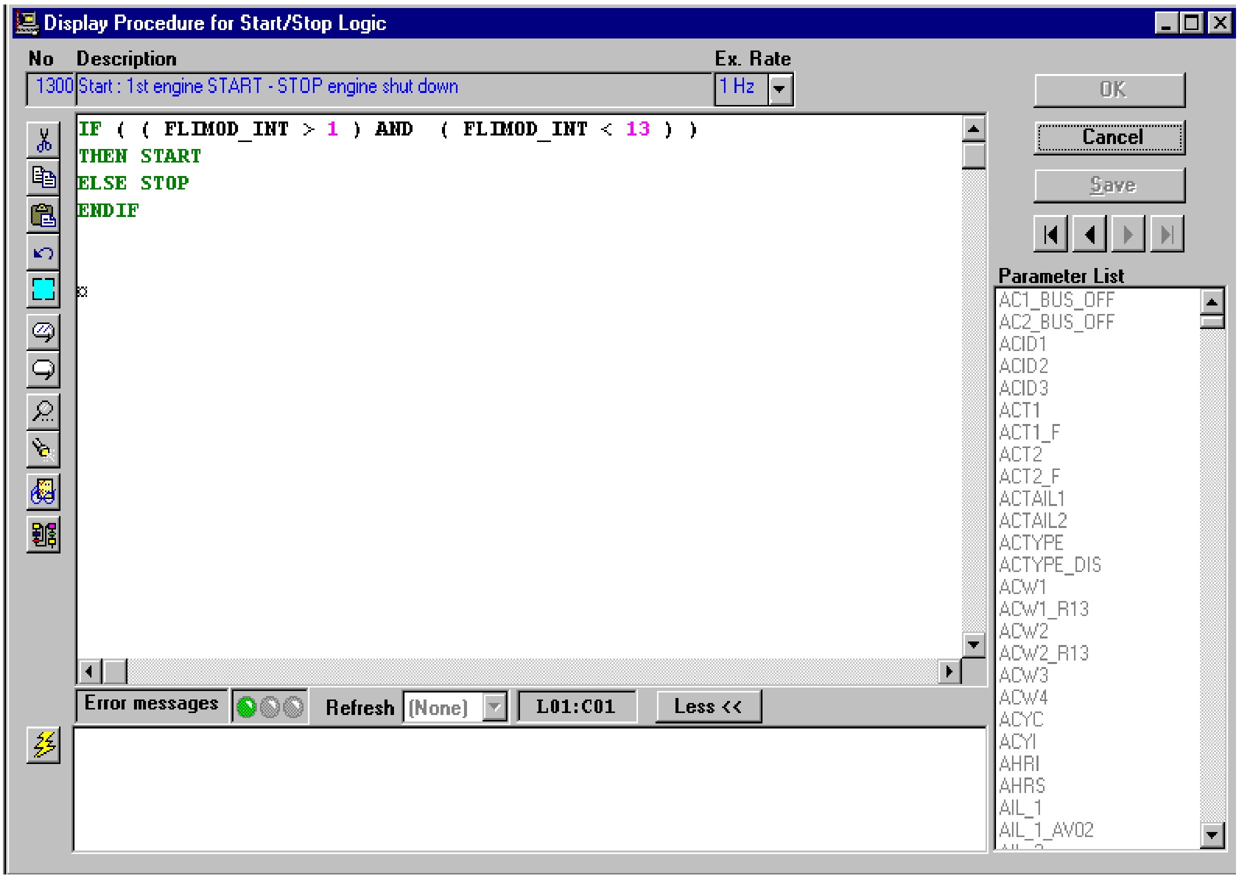
4.3.4.2. AIDS/ACMS readout tool

It allows the operator to view the reports.

4.3.4.3. Data processing analysis

Once the in-flight data have been retrieved, they can be processed and analyzed with the APM program.

4.3.4.4. Example of SFIM GSE – Triggering condition programming



4.4. The Cruise Performance Report

In brief, the recording systems described above produce a series of reports. Only the Cruise Performance Report or DMU/FDIMU report number <02> (CPR<02>) is of interest for aircraft performance monitoring.
The present paragraph describes this particular file and may be considered as a reference.

4.4.1. General

The DMU/FDIMU is configured at the delivery of the aircraft to produce one report per hour. This may be changed via reprogramming the DMU/FDIMU via the Ground Support Equipment (GSE). It is the operator's responsibility to update the DMU/FDIMU software.

The report <02> provides aircraft and engine data recorded in stabilized cruise. Some stability conditions and triggering conditions are mandatory so that the DMU/FDIMU can store data on the report. The stability criteria are given in this paragraph.

The CPR<02> can be obtained:
- on a piece of paper via a printout on the cockpit printer
- in digital format (on a diskette, on the DAR optical disk (A330/A340 only), on a PCMCIA card (A320 FAM aircraft only) or via transmission by ACARS)

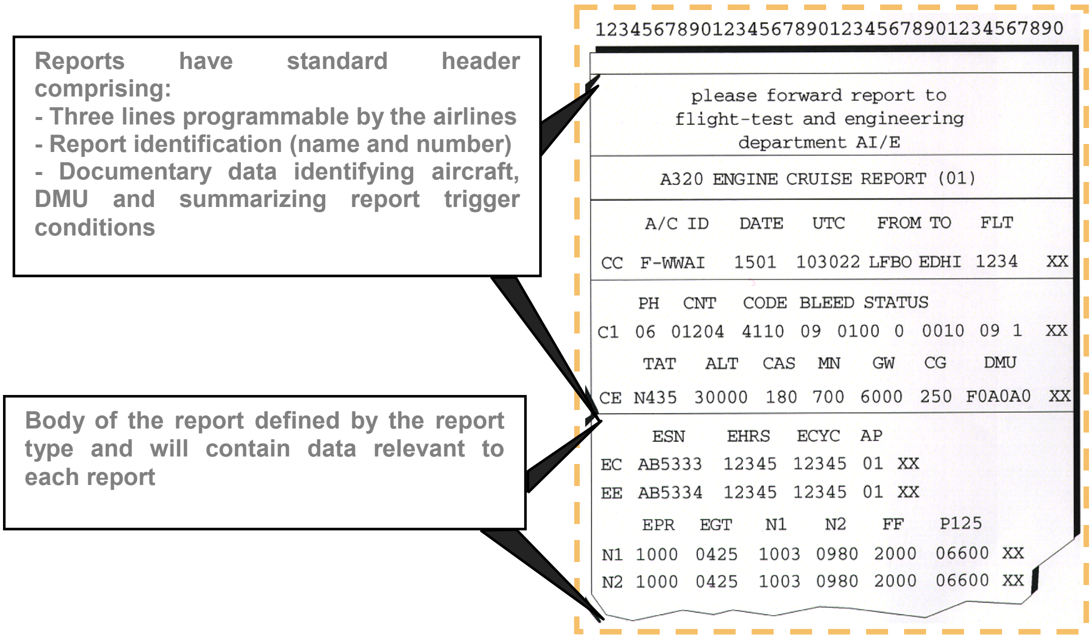
The advantages of automatic recording are that::
- all data required for cruise performance analysis are stored in the CPR<02> format
- the report in digital format can be used "as is" without any additional handling operations. When the report is not in a digital format, the same typing operations as in case of manual recording will have to be done by the operator.

4.4.2. Two report formats

There are actually two different formats of CPR<02> files depending on the DMU/FDIMU interface used for report retrieval.

4.4.2.1. Printed report, diskette or PCMCIA dumped reports

These reports have the following format.



4.4.2.1.1. Example of CPR<02> for an A319 aircraft fitted with EPR controlled Engines

```
A319 CRUISE PERFORMANCE REPORT <02>

     A/C          DATE     UTC      FROM     TO       FLT
CC AI-001       feb99    113412  LFBO     LFBO     05080

     PH   CNT      CODE         BLEED STATUS          APU
C1   06   00514    5000        48 0010 0 0100 48    0

     TAT       ALT       CAS     MN     GW        CG  DMU/SW
CE   N240      33000.    276     780    6500      330 I51001
CN   N240      33000.    276     780    6500      330 I51001

     ESN           EHRS     ECYC         AP   QA   QE
EC   0100003      03000    00600        71   12   12
EE   0100004      03000    00600        71

     EPR       N1       N2       EGT      FF       P125
N1   1284      8321     8320     3580     1283     06892
N2   1284      8320     8321     3580     1283     06892

     P25      T25      P3       T3       P49      SVA
S1   11155    0557     1243     4313     06150    069
S2   11137    0556     1231     4324     06142    068

     BAF ACC      LP   GLE PD   TN          P2     T2
T1   094 082      00   035 40   180         04219 N255
T2   096 082      00   023 36   180         04215 N271

     ECW1     ECW2     EVM      OIP    OIT    OIQH
V1   03D01    00008    08000    245    121    0000
V2   03D01    00008    08004    234    120    0000

     VB1    VB2      PHA
V3   024    005      043
V4   007    001      078

     WFQ      ELEV     AOA      SLP      CFPG     CIVV
X1   02652    N003     0025     0000     N0001    0001
X2   02772    N001     0025     0000     N0000    0003

     RUDD     RUDT     AILR     AILL     STAB     ROLL     YAW
X3   0000     0008     N001     N006     N008     N000     N000

     RSP2     RSP3     RSP4     RSP5     FLAP     SLAT
X4   N000     0000     0000     0000     0000     0000
X5   0000     0000     0000     0000     0000     0000

     THDG     LONP     LATP     WS    WD     FT     FD
X6   1905     E0019    N450     050   011    0110   XXXX
X7   XXXX     E0019    N450     050   011    0108   0785
```

4.4.2.1.2. Example of CPR<02> for an A319 aircraft fitted with N1 controlled Engines

```
A319 CRUISE PERFORMANCE REPORT <02>

    A/C         DATE    UTC     FROM    TO      FLT
CC  AI-001      feb02   110117  LFBO    LFBO    05080

    PH  CNT     CODE          BLEED STATUS        APU
C1  06  00514   5000          48 0010 0 0100 48   0

    TAT       ALT       CAS    MN    GW        CG  DMU/SW
CE  N240      33000.    276    780   6500      330 C51001
CN  N240      33000.    276    780   6500      330 C51001

    ESN         EHRS    ECYC        AP  QA  QE
EC  0100003     03000   00600       71  12  12
EE  0100004     03000   00600       71

    N1      N1C     N2     EGT      FF      PS13
N1  868     869     875    5850     1320    06892
N2  868     869     875    5850     1320    06892

    P25     T25     P3      T3      P49     SVA
S1  11155   0557    1243    4313    06150   069
S2  11137   0556    1231    4324    06142   068

    BAF ACC     LP  GLE PD  TN         P2    T2
T1  094 082     00  035 40  180        04219 N255
T2  096 082     00  023 36  180        04215 N271

    ECW1    ECW2    EVM     OIP   OIT   OIQH
V1  03D01   00008   08000   245   121   0000
V2  03D01   00008   08004   234   120   0000

    VB1   VB2     PHA
V3  024   005     043
V4  007   001     078

    WFQ     ELEV    AOA     SLP     CFPG    CIVV
X1  02652   N003    0025    0000    N0001   0001
X2  02772   N001    0025    0000    N0000   0003

    RUDD    RUDT    AILR    AILL    STAB    ROLL    YAW
X3  0000    0008    N001    N006    N008    N000    N000

    RSP2    RSP3    RSP4    RSP5    FLAP    SLAT
X4  N000    0000    0000    0000    0000    0000
X5  0000    0000    0000    0000    0000    0000

    THDG    LONP    LATP    WS   WD    FT    FD
X6  1905    E0019   N450    050  011   0110  XXXX
X7  XXXX    E0019   N450    050  011   0108  0785
```

4.4.2.1.3. Parameters taken from report <02>

Report output	APM input	Remarks	Codification example
A/C	TAILNO	Tail Number	XXXXXX
DATE	DATE	Date	AAA99
FLT	FLNO	Flight Number	9999
UTC	FCASE	Hour/min. taken far case ident	999999
CODE	-	Trigger logic code (see below for details)	5000 or 4000 on all fly-by-wire aircraft depending on the engine type fitted on the aircraft.
DMU/SW CODE		For aircraft/engine type check and report format variations. The last three digits allo stable frame identification	XXXXXX X=Engine type (C=cfm, I=IAE) X=Engine version 1…8 X=Hardware number 0..9 XXX=Software version(001..009)
		Two values read. Enter the mean value.	
		Standard altitude (eg –500 or 35000 ft)	
ALT	ALT	Mach Number (eg 0.78)	X9999 (eg N0500 or 35000)
MN	MACH	Total Air Temperature (eg –10°C)	999 (eg 780)
TAT	TAT		X999 (eg N100)
		Values from two systems read. Enter the mean value.	
GW	MASS	Gross Weight	9999
CG	CG	Center of gravity	999
CFPG	FPAC	Calculated Flight Path Acceleration (-0.9999 to 4.0000 g)	N9999 to 40000
CIVV	VV	Calculated Inertial Vertical Speed (-999 to 999 ft/min)	N999 to 0999
THDG	THDG	True Heading (0° to 359.9°)	0000 to 3599
LATP	LAT	Latitude (N89.9° to S89.9°)	N899 to S899
WS	CWI	Wind speed (0 to 100 kt)	000 to 100
WD	DWI	Wind direction (0° to 359°)	000 to 359
FT	AFT	Fuel Temperature (-60.0° to 170°C)	N600 to 1700
FD	AFD	Fuel Density (0 to 0.999 kg/l)	0000 to 0999
		for engine 1 to 2	
ESN	ESN	Engine serial number	XXXXXX
N1 (EPR)	REG	N1 (0 to 120%) or EPR(0.6 to 1.8)	0000 to 1200 or 0600 to 1800
FF	FFA	Fuel flow (0 to 7000 kg/h/eng)	0000 to 7000
EGT (TGT)	EGT	Exhaust gaz Temperature (-55° to 999.9°C)	N550 to 9999

Report output	APM input	Remarks	Codification example
BLEED STATUS“	WBLL WBLR	Left engine Righ engine Eg. 99 0100 0 0010 99	99 LH Pack flow 0.99 kg/s LH Wing AI/V Fully Closed=0 Eng1 NAC AI/V Open=1 Eng 1 PRV Fully Closed=0 Eng 1 HPV Fully Closed=0 Cross Feed V Fully Closed=0 Eng 2 HPV Fully Closed=0 Eng 2 PRV Fully Closed=0 Eng 2 NAC AI/V Open=1 RH Wing AI/V Fully Closed=0 99 RH Pack flow 0.99 kg/s
APU		Eg. 1	Apu bleed Valve State Open=1
	FLHV	not on report.	

4.4.2.2. Report transmitted by ACARS

As ACARS transmissions are expensive, when the CPR<02> is transmitted to the ground, the format of the received file is slightly different so as to decrease the length of the file and its size.

The sample file below is an example of ACARS transmission. It contains two points recorded for the same aircraft registered AI-002.


```
-  A02/A32102,1,1/CCAI-
002,APR11,153333,EFOU,EFHK,0368/C106,34201,5000,54,0010,0,0100,54,X/CEN17
3,31019,290,782,7080,242,C73001/CNN171,31053,290,783,7080,242/ECSN0001,00
208,00256,00165,73,33,22/EESN0002,00208,00260,00165,73/N10844,0845,0928,5
947,1428,07947/N20844,0845,0929,5888,1443,07827/S115521,0712,1537,4321,39
80,020,006/S215528,0713,1531,4308,4019,018,002/T1099,096,026,46,045,0
6271,0336/T2099,096,023,46,036,06335,0305/V105,00,287,168,03,00,00000/V20
2,02,135,105,01,00,00000/V3XX,XX,XXX,XXX,XXXX/V4XX,XX,XXX,XXX,XXXX/V511,0
1,283,046,0916/V612,02,182,268,0916/V7044,083,00081,2222222222111/V8043,
082,00061,2222222222111/X102541,N002,0017,0000,00000,0000/X202527,0000,0
014,0000,00000,N000/X3N000,0004,N006,N007,N006,N002,N000/X40000,0000,0000
,0000,0000,0000/X50000,0000,0000,0000,0000,0000/X61891,E0256,N625,056,278
,N000,0807/X71893,E0255,N624,055,279,0001,0806,/
-  A02/A32102,1,1/CCAI-
002,APR11,104839,LFPG,EFHK,0872/C106,33901,5000,50,0010,0,0100,50,X/CEN25
6,37008,256,790,6865,277,C73001/CNN255,37041,256,791,6865,277/ECSN0001,00
205,00253,00163,73,14,07/EESN0002,00205,00257,00163,73/N10868,0868,0934,6
281,1296,06317/N20868,0869,0935,6209,1308,06231/S112372,0668,1325,4367,42
28,001,004/S212375,0670,1321,4360,4253,N00,001/T1099,079,026,42,042,0
4750,0103/T2099,079,022,43,028,04795,0094/V105,02,303,142,03,00,00000/V20
6,02,137,112,01,00,00000/V3XX,XX,XXX,XXX,XXXX/V4XX,XX,XXX,XXX,XXXX/V511,0
1,283,046,0916/V612,02,182,268,0916/V7043,087,00061,2222222222111/V8042,
087,00081,2222222222111/X103612,N003,0022,0000,00004,N000/X203525,N000,0
020,0000,00004,N000/X3N000,0006,N004,N007,N006,0000,N000/X40000,0000,0000
,0000,0000,0000/X50000,0000,0000,0000,0000,0000/X60293,E0074,N543,030,250
,N011,0812/X70293,E0075,N543,028,252,N012,0813,/
```

The correspondence between this file and the *standard* report can be obtained by tracking the lines identifiers. For instance, the aircraft registration is identified as A/C in the standard report. It is written on line CC.
In the ACARS-transmitted file, the first characters are:
- A02/A32102,1,1/CCAI-002 […]
Each data is separated by a comma ",". After a slash "/", the line identifier is written. So in this record, we can read AI-002 is the aircraft registration.

4.4.2.3. Report specification

Both Print-like report and ACARS report have been defined in accordance with a specification.

The exhaustive description of the print-like file is given to the operators in another part of the Airbus documentation, the Aircraft Maintenance Manual (AMM) in section 31-36-00. Read *Chapter H-Appendix 5 – AMM extracts, Cruise Performance Report <02> description*.

As far as the ACARS format is concerned, no specification is made available to the customers. Airbus is ready to provide such a description of the ACARS report upon request.

4.4.3. The trigger logic

A trigger logic is a set of conditions checked before the DMU/FDIMU generates a report.
There are several trigger logics for the cruise performance report <02>. For example, one is for the manual selection via the MCDU; another one is for the use of the remote print button as an order for the data collection.
In particular, trigger logic n°5000 (or 4000 depending on the aircraft model) is called the *best stable frame* report logic. This trigger logic aims at detecting stable flight conditions in order to avoid report triggering in flight phases where parameters are of no use.
Airbus recommends the use of these reports for aircraft performance-monitoring purposes.

The AIDS/ACMS Cruise Performance report <02> is generated when the DMU/FDIMU detects that the conditions defining a stable cruise are met. When the cruise flight phase is reached, this stability searching is made by monitoring some aircraft parameters.
When the variation of all these parameters are within a range defined for each one of them during a customizable time-period, then the stable cruise conditions are met and the report is generated. If the conditions are not met, the report <02> will not be generated.
Note that the operator is not allowed to change any of the trigger limits.

An aircraft quality number characterizes each report. It is defined thanks to the below formula:

$$QA = \sum W(N) \times \frac{VAR(N)}{TOL(N)^2}$$

where N is parameter number N (can be the N1, fuel flow…)
W(N) is a weighing factor (between 0 and 1)
VAR(N) is the individual variance
TOL(N) is the individual variation value

The lower the quality numbers the better the stable frame report. QA varies between 0 and 999. Common values seen in routine monitoring are around 40. The quality numbers are not used as a trigger condition but are used to detect the best report during a searching period.
The operators can use it so as to eliminate possible irrelevant recordings. Most of the time, quality numbers are not used because it is hard to get some points, especially for short-range flights.

Example of trigger logic and conditions for an A320 aircraft fitted with IAE engines
The DMU/FDIMU generates the CPR<02> based on flight hours or flight legs. The choice is programmable via the GSE.
Depending on the basis for searching, the DMU/FDIMU searches in cruise phase for report generation with stable frame criteria where the best aircraft quality number is calculated. The report with the best quality number is then stored in the report buffer.

The basic DMU/FDIMU configuration for the A320 aircraft is:
1. Searching time frame: 1 hour
2. Observed data during five sub-periods of 20 seconds each. The best period is retained thanks to the quality number.
3. The stability criteria, which must be met are:

Parameter	Limit
Inertial Altitude	150 feet
Ground Speed	6 kt
Roll Angle	0.8 degrees
TAT	1.1 degrees C
N2	0.9 %
EGT	18 degrees C
Vertical Acceleration	0.03 g
Mach Number	0.008 Mach
N1	1.6 %
P2	0.05 psia
Fuel Flow	100 kg/h
EPR	0.035

4.5. Data analysis procedure

The analysis procedure is much simpler compared to the case when performing manual recordings because the stability criteria were already checked by the DMU/FDIMU before parameters are recorded. As of a consequence, no further assessment of the parameter stability is required.

All the input data were stored in the Cruise Performance Report <02> apart from a few parameters that are given down below:

- The fuel Lower Heating Value: as this value cannot be read in the report, it must be obtained from another source. When performing an audit, a fuel sample will be analyzed and the corresponding FLHV will be identified. In case of routine performance monitoring, the FLHV will be assumed equal to a standard value. Most commonly, the value 18590 BTU/LB is used for analysis. Yet some precautions have to be taken, in order not to bias the calculated different fuel factors (see *Chapter F-Using monitored fuel factor*).

- The year of recording may not be stored in reports for some aircraft type. The year should then be provided for the analysis and for history purposes.

- When the parameters are automatically recorded thanks to the DMU/FDIMU, non relevant points are simply eliminated (for instance, points which are recorded below FL200 are not taken into account). It may happen that such points are recorded due to DMU/FDIMU malfunctions. As a consequence, particular attention is required so as to assess the validity of each particular point. This check is often performed when a discrepancy in the cruise performance analysis is noticed on a few points.

The analysis of the resulting points can be performed with an Airbus specific tool, based on the specific range method: the APM program. Airbus has implemented a specific routine that allows automatic loading of cruise performance reports number 02, when in digital format.

Statistical elimination can be selected before the actual analysis with the APM program. For each parameter (fuel flow, N1/EPR,…), the mean value and the standard deviation is calculated over all the records. The user can then filter the records so as to get rid of inappropriate low quality readings.
Two filters are implemented in the APM program:
- standard elimination which discards the points which are outside a 95%-confidence interval
- pre-elimination window which enables the user to eliminate the parameters which are outside a user's defined window, which is centered on the mean value

D. CRUISE PERFORMANCE ANALYSIS

Several Airbus tools are available to perform cruise performance analysis. The Airbus Aircraft Performance Monitoring (APM) program comes first for routine aircraft performance monitoring due to the amount of data to process. Indeed, this program features a DMU/FDIMU report loading function, which relieves from tedious handling operations.

Some other Airbus tools (the IFP program…) are available for these analyses and may be used. The tool choice is at the airline's discretion.

The following lines deal with the software aspect of cruise performance analysis. The pre-requisite for this chapter is a basic comprehension of how to get the parameters from the aircraft, as well as general background on the specific range method itself.

1. THE BOOK LEVEL

As a reminder, the *aircraft performance book level* is established by the aircraft manufacturer and represents a fleet average of brand new aircraft and engines. This level is established in advance of production and is derived from flight tests. Normal scatter of brand new aircraft leads to performance above and below the book value. The performance data given in the Airbus documentation (Flight Crew Operating Manual) reflects this book value.

The high-speed book value data is stored in the high-speed performance databases used by Airbus performance software such as the IFP, the FLIP or the APM programs. This aircraft Performance model is built based on results from extensive performance flight tests: the IFP model.
Most of the Computerized Flight Plan systems as well as the published Performance tables in the Flight Crew Operating Manual and in the Quick Reference Handbook use the IFP model.

2. A TOOL FOR ROUTINE ANALYSIS : THE APM PROGRAM

2.1. Introduction

The Airbus Aircraft Performance Monitoring program (APM) is devoted to high-speed performance analysis of all Airbus aircraft. It is useful a software anytime performance analysis is required. Indeed, the APM program enables to compare the aircraft cruise performance level (fuel consumption, engine parameters, specific range) as recorded during flight to book value performance data as stored in the aircraft's high speed performance databases.

It calculates the deviation of flight parameters such as fuel flow, and N1/EPR engine parameters from nominal book values. The end result is a delta specific range, which reflects how far the aircraft is from its book value.
The specific range can of course be worse but also better than the book level because this book level only represents an average performance level over a number of brand new aircraft/engine combinations.

The delta specific range is the monitored fuel factor (opposite sign), which will allow the operator to tune:
- the aircraft FMS flight plan on board the aircraft,
- the computerized flight planning and every high-speed performance related studies in maintenance servicing, engineering or dispatch of the aircraft.

2.2. Basics

The APM calculates aircraft cruise performance in a so-called deterministic way. That is with the use of mathematical methods from the fields of probability, optimal estimation or filtering techniques and by using familiar equations of lift, drag and engine thrust in stabilized conditions during cruise. The analysis is called the Specific Range method. For each flight case, in flight recorded data is used to calculate a measured Specific Range (SR, distance covered per unit of fuel burnt). Results are then compared to the SR that is predicted for the given flight conditions (weight, altitude, TAT, Mach) based on a theoretical model. Following which, the program determines a deviation in specific range. Furthermore, it also enables a distinction between airframe and engine influence.
By comparing book and measured values of engine power setting, fuel flow and exhaust gas temperature, a set of deviation parameters is being calculated to be produced in a result file.

The APM program schematically works as described in the following diagram. Orange boxes represent the theoretical model, blue boxes represent actual data.

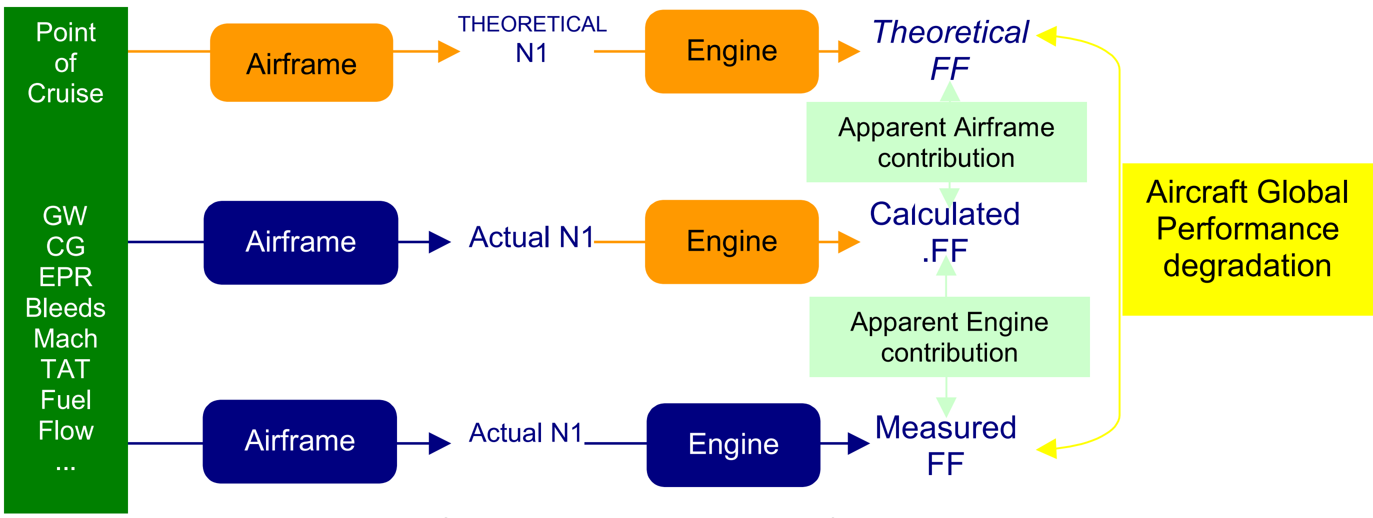


Figure D1 – Schematic APM process (FF stands for Fuel Flow)

The input file contains information about Mach number, altitude, TAT, aircraft gross weight, CG location, bleed flow, FPAC (Flight Path Acceleration), IVV (Inertial Vertical Velocity).

2.3. The input data

This paragraph details the input, which the APM program needs for cruise performance analysis.
Following is a reference table for cross-checking that all required parameters can be accessed easily.

Label	Parameter	Unit	Comments	Influence on the result
AILNO	Aircraft Tail Number	(–)		None
DATE	Date	YYMMDD		None
FLNO	Flight Number	(–)		None
FCASE	Flight Case or DMU/FDIMU recording time	1-99	Number of data of a same flight. If no value is set, the program sets a "1".	None
		hhmm	Time at which the performance point was taken in flight.	None
ESN	Engine serial number	(–)		None
ALT	Altitude	(ft)	From the two air data computers (ADC)	
MACH	Mach number	(–)	From the two air data computers (ADC)	
TAT	Total Air Temperature	(°C)	From the two air data computers (ADC)	
MASS	Aircraft mass (weight)	(kg or lb)		Impact on DFFA
CG	Center of Gravity	(%)		Impact on DFFA
FPAC	Flight Path Acceleration	(g)	Horizontal acceleration measured in g.	Impact on DFFA
VV	Vertical Velocity	(ft/min)	Vertical acceleration	
THDG	True Heading	(°)	Optional - used only if gravity correction activated.	
LAT	Latitude	(°)	Optional - used only if gravity correction activated.	
CWI	Wind speed	(kt)	Optional - used only if gravity correction activated.	
DWI	Wind direction	(°)	Optional - used only if gravity correction activated	
AFT	Average fuel temperature	(°C)	NOT ACTIVE	None
AFD	Average fuel density	(l/kg)	NOT ACTIVE	None
REG	N1 - Power setting EPR - Power Setting	(%) (–)	Depends on engine type EPR for IAE, RR and P&W engines, N1 for GE and CFM engines.	

FFA	Actual fuel flow	(kg/h, lb/h)	Fuel flow for each engine (FFA1, FFA2, ...)	Impact on DFFB
Label	Parameter	Unit	Comments	Influence on the result
EGT	Exhaust gas temperature	(°C)	To be set for each engine (EGT1, EGT2, ...)	
FLHV	Fuel lower heating value	(BTU/lb)		Impact on DSR
WBLL	Engine bleed flow (left)	(kg/s or lb/s)	Engine 1 flow (twin engine A/C) or sum of engines 1 and 2 (4 engine-aircraft)	Impact on DFFA
WBLR	Engine bleed flow (right)	(kg/s or lb/s)	Engine 2 flow (twin engine A/C) or sum of engines 3 and 4 (4 engine-aircraft)	Impact on DFFA
BLC	Engine bleed code (alternatively to WBLL and WBLR)	(–)	0 ... off (no bleed) E ... economic (low) N ... normal H ... high (max)	Impact on DFFA AC NORM / AI OFF is recommended bleed configuration for performance monitoring recording.

2.4. APM output data

Before detailing the APM output data, the following lines will remind the principle of the Airbus APM program.

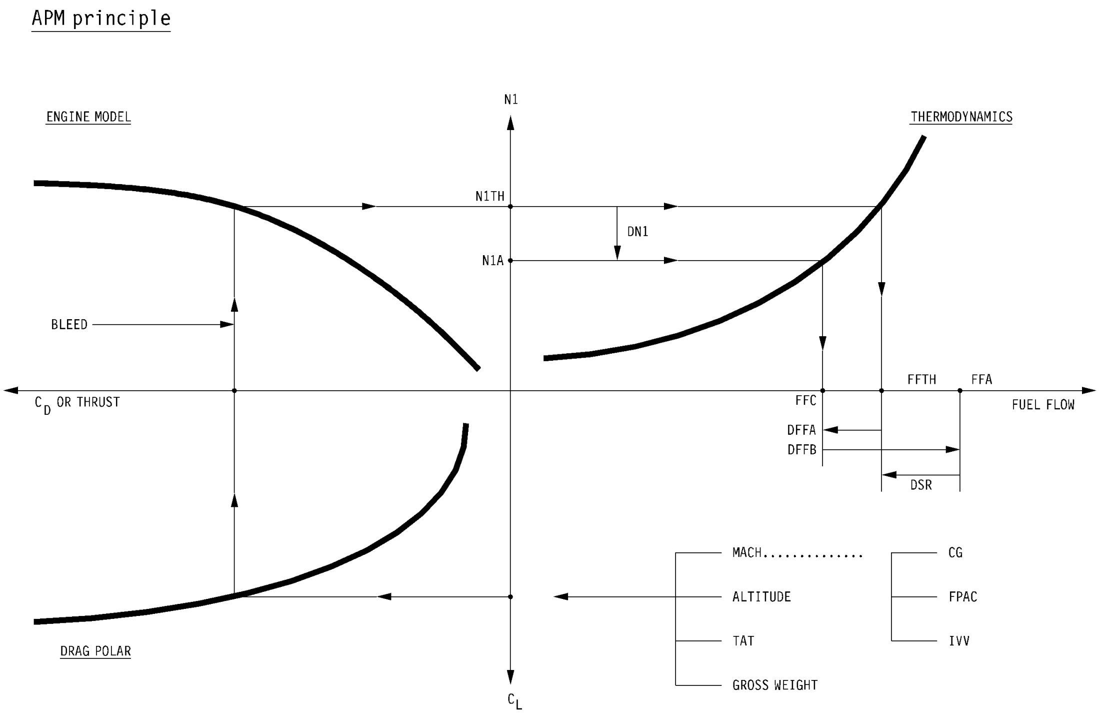


Figure D2 – Principle of the APM program calculation

Based on the flight mechanics equations, and thanks to some of the parameters recorded in-flight, it is possible to determine the amount of lift or lift coefficient (C_L). The aerodynamic characteristics of the aircraft are known from the IFP model. The drag to lift relation and the calculated lift allows to get the corresponding amount of drag (C_D).
In the flight mechanics equation, the drag is the required thrust to maintain the flight. The thrust at N1 (in the example) is deduced from the IFP engine model, giving us the N1 as per the book level or theoretical N1 (N1TH).

Second, at a given N1, the IFP model allows us to determine what the fuel flow is. The fuel flow corresponding to the measured N1 (N1A) is called the Calculated Fuel Flow (FFC). The fuel flow corresponding to the theoretical N1 (N1TH) is called the theoretical fuel flow (FFTH).

The APM output file provides for each engine:

. DN1 = N1 – N1TH or DEPR = EPR - EPRTH

. DFFA = (FFC - FFTH) / FFTH x 100 (%)

. DFFB = (FFA - FFC) / FFC x 100 (%)

The APM output file also provides average figures for the two (or four) engines:

. DFFAM = (FFCM - FFTH) / FFTH x 100 (%)
. DFFBM = (FFAM - FFCM) / FFCM x 100 (%)

. DSR = (FFTH - FFAM) / FFAM x 100 (%).

DSR represents global aircraft performance degradation (in %), in terms of Specific Range degradation.

DFFB is the deviation of fuel flow due to engine deterioration.

DFFA is the deviation fuel flow due to "apparent" airframe deterioration.

Some aspects need to be underlined to better appreciate results of the APM program:

DFFB is only linked to N1/EPR and FF recordings, and is independent of the EPR thrust relationship and of the associated engine model. This means that a high level of confidence can be given to the DFFB value.

DFFB is also linked to the fuel lower heating value (FLHV). The Airbus nominal value is 18590 Btu/lb. The FLHV is used to calculate theoretical parameters such as the fuel flow (FFTH), the N1/EPR (N1TH/EPRTH).

DFFB is also linked to the calibration of the engine fuel-flow meters.

DFFB results can be confirmed by a separate EGT analysis performed by the engine maintenance specialists in the airline.

DFFA is linked to flight conditions. Flight conditions are the main source of error, especially inaccurate aircraft gross weight (payload based on standard weights) and non-negligible FPAC. Therefore, the DFFA value needs to be interpreted with the utmost precaution.

In other words, a high DFFA does not necessarily indicate a high aerodynamic deterioration of the airframe. An altered EPR/thrust relationship versus the reference engine can be responsible for part of the deviation. This is also valid for a brand new engine.

All APM results should be compared to the result of the performance tests carried out during the first flight of the aircraft. This is valid provided the engines on the wings are the same. Some differences can be expected because the first flight of the aircraft is outside normal operational constraints.

2.5. The APM statistical analysis

The aim of this paragraph is to give a reminder and some explanations on the way statistics were implemented in the APM program.

2.5.1. General

The APM program features a statistical elimination of measurement points. For the output results DN1/DEPR, DFFA, DFFB, and DSR, the mean value and the standard deviation are calculated.

Whenever any point of measurement result is outside the 95 % interval of confidence (μ - 2 σ, μ + 2 σ) it is eliminated (replaced by a trailing "*") and not included in the relevant parameter mean value and standard deviation.

A low standard deviation value provides a high level of confidence, since it means that all results are consistent and within a limited range.

2.5.2. Mean value (μ)

The simplest statistic is the mean or average. It is easy to calculate an average value and use that value as the "target" to be achieved.

The mean value characterizes the "central tendency" or "location" of the data. Although the average is the value most likely to be observed, many of the actual values are different from the mean. When assessing control materials, it is obvious that technologists will not achieve the mean value each and every time a check is being performed. The values observed would show a dispersion or distribution around the mean, and this distribution would need to be characterized to set a range of acceptable control values.

2.5.3. Standard deviation (σ)

The dispersion of values around the mean value is predictable and can be characterized mathematically through a series of steps, as described below.

1. The first mathematical manipulation is to sum () all individual points and calculate the mean or average.
2. The second manipulation is to subtract the mean value from each control value. This term is called the difference score. Individual difference scores can be positive or negative and the sum of the difference scores is always zero.
3. The third manipulation is to square the difference score to make all the terms positive. Next the squared difference scores are summed.

4. Finally, the predictable dispersion or standard deviation (σ) can be calculated as follows:

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{(n-1)}}$$

where	xi	measurement number i
	$\bar{x}$	mean value of all the measurement points
	n	number of measurement points

2.5.4. Degrees of freedom

The "n-1" term in the above expression represents the degrees of freedom. Loosely interpreted, the term "degrees of freedom" indicates how much freedom or independence there is within a group of numbers. For example, if you were to sum four numbers to get a total, you have the freedom to select any numbers you like. However, if the sum of the four numbers is supposed to be 92, the choice of the first 3 numbers is fairly free (as long as they are low numbers), but the last choice is restricted by the condition that the sum must equal 92. For example, if the first three numbers chosen at random are 28, 18, and 36, these numbers add up to 82, which is 10 short of the goal. For the last number there is no freedom of choice. The number 10 must be selected to make the sum come out to 92. Therefore, the degrees of freedom have been reduced by 1 and only n-1 degrees of freedom remain. In the standard deviation formula, the degrees of freedom are n minus 1 because the mean value of the data has already been calculated (which imposes one condition or restriction on the data set).

2.5.5. Variance

Another statistical term that is related to the distribution is the variance, which is the standard deviation squared (variance = σ^2). The STANDARD DEVIATION may be either positive or negative in value because it is calculated as a square root, which can be either positive or negative. By squaring the STANDARD DEVIATION, the problem of signs is eliminated. One common application of the variance is its use in the determination whether there is a statistically significant difference in the imprecision between different methods.

In many applications (especially in the APM program), the STANDARD DEVIATION is often preferred because it is expressed in the same units as the data. Using the STANDARD DEVIATION, it is possible to predict the range of control values that should be observed if the method remains stable. The STANDARD DEVIATION is often used to impose "gates" on the expected normal distribution of control values. Additional gates can also be defined thanks to the APM program.

2.5.6. Normal or Gaussian distribution

Traditionally, after the discussion of the mean, standard deviation, degrees of freedom, and variance, the next step is to describe the normal distribution (a frequency polygon) in terms of the standard deviation "gates”.

The normal distribution is a continuous probability distribution, which is used to characterize a wide variety of types of data. It is a symmetric distribution and is completely determined by its mean and standard deviation. The normal distribution is particularly important in statistics because of the tendency for sample means to follow the normal distribution.

The figure hereafter is a representation of the frequency distribution of a large set of values obtained by measuring a single control material. This distribution shows the shape of a normal curve. Note that a "gate" consisting of ±1 σ accounts for 68% of the distribution or 68% of the area under the curve, ±2 σ accounts for 95% and ±3 σ accounts for >99%. At ±2 σ, 95% of the distribution is inside the "gates," 2.5% of the distribution is in the lower or left tail, and the same amount (2.5%) is present in the upper tail. This curve is like an error curve that illustrates that small errors from the mean value occur more frequently than large ones.

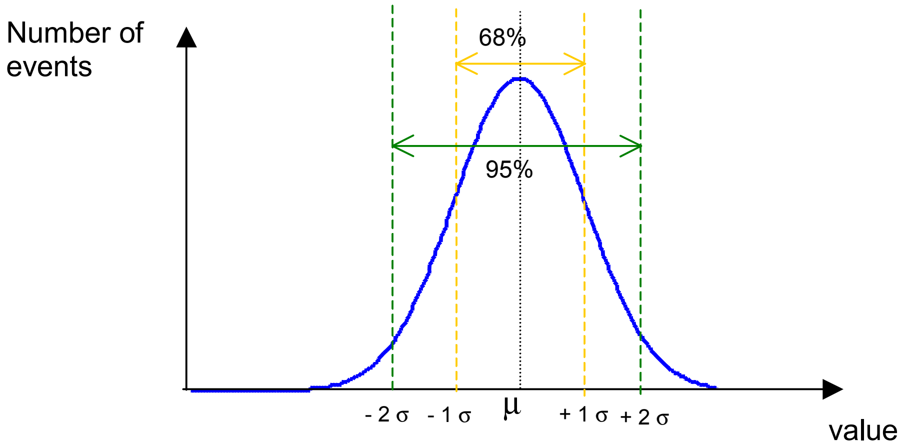


Figure D3 – Gaussian distribution law

The normal distribution is also known as the Gaussian distribution after its inceptor, Johann Carl Fredirich Gauss.

2.5.7. Confidence interval

A confidence interval is a statistic constructed from a set of data to provide an interval estimate for a parameter. For example, when estimating the mean value of a normal distribution, the sample average provides a point particular estimate or best guess about the value of the mean. However, this estimate is almost surely not exactly the correct physical value. A confidence interval provides a range of values around that estimate to show how precise the estimate is. The confidence level associated with the interval, usually 90%, 95%, or 99%, is the percentage of times in repeated sampling that the intervals will contain the true value of the unknown parameter.

Confidence intervals rely on results from the normal distribution.

2.6. The APM archiving system

The APM program enables the storage of aircraft performance data in libraries for long term trend monitoring.
Both input data coming from measurements and output data issued from the analysis can be stored in libraries. This feature enables to monitor the aircraft degradation trend with time so as to identify any corrective actions to be taken. It also enables to obtain average results over all the tail numbers of the fleet.
A nice-handling interface provides an efficient and proper data management via these so-called APM libraries.

2.7. Some nice-to-knows about the APM

To determine the aircraft performance level with accuracy, a certain number of parameters must be recorded prior to take off and in-flight.

2.7.1. Influencing factors

Chapter *B-Background* introduced to the aircraft performance monitoring methods and reminded the possible causes for bias and/or scatter on the analysis.

The APM program has evolved over the past twenty years so as to account for automated correction calculations to take into account part of the influencing factors.

Amongst these, the Coriolis effect is taken into account. Entering the aircraft position and heading will make the influence calculated automatically.

An energy correction is included to the APM to take into account variations in kinetic (FPAC – acceleration / deceleration) and potential energy (IVV - inertial vertical velocity). The energy variations due to horizontal and/or vertical accelerations are taken into account through the values recorded in-flight (flight path acceleration, inertial vertical velocity). This reduces the scatter of the APM results but is only valid for small movements around the equilibrium point respecting the stabilization criteria. It boils down to remain in the linearized part of the equations of movement programmed into the APM.

Note: No FPAC / IVV, C.G. corrections taken into account in the A300B2 / B4 program.

The other corrections (such as loss/gain of performance due to isobar slope, …, etc, …) are not taken into account and as a result will introduce bias and/or scatter on the output result. The purpose of routine monitoring being to monitor the trend of the aircraft performance, the APM analysis does not require any further corrections as long as the same assumptions are kept for the analysis (especially the fuel Lower Heating Value).

2.7.2. Aircraft bleed configuration

The APM program can use DMU cruise performance report number 02 (CPR<02>) as an input file. One of the entries, which is required by the APM program, is the bleed flow for each pack. The cruise performance report 02 contains the pack bleed flows.

As far as the bleeds are concerned,
- No cruise performance report is produced whenever the configuration is not as required: anti ice OFF, cross feed valve open, symmetrical valve positions
- A given record is not analyzed whenever the recorded difference between pack flow 1 and pack flow 2 is higher than 10%.

Focusing on the second item, the following is worth mentioning it.

The bleed flow asymmetry has an impact on the theoretical fuel flow (FFTH). The APM program must use the mean value of left and right bleed flows to iterate the FFTH. A 10%-margin was retained so as to avoid error in calculating the DSR greater than 0.1%. More precisely, when the data is read from a CPR<02>, the bleed flow is defined by pack left/right flows. The APM program cope with these two values by:
- averaging both values to get a single value,
- reading in the engine high speed database the related fuel flow by interpolating between two bleed ratings (OFF, LO/ECON, NORM, HI).

In practice, bleed flows between both packs can be different. This item is more significant on A320 aircraft types, where the old standard of Flow Control components (including flow control valves) had a less restrictive industrial tolerance than the newer standard. Airbus published a specific Service Information Letter (SIL) to inform airlines of this issue. This SIL is given in *Chapter H - Appendix 4 – Airbus Service Information Letter 21-091*.

The APM program will evidence that some troubleshooting may be required on this specific ATA 21 item. The Trouble Shooting Manual (TSM) contains a couple of entries in the form of crew observations in section 21-51. The procedures will lead relevant trouble shooting procedures.

2.7.3. Aircraft model specifics

Two aspects need to be underlined to appreciate the results of the APM program.

2.7.3.1. The thrust / drag uncertainty

The aircraft drag assessment assumes the invariability with time of thrust at N1/EPR relationship. However a scatter exists from one engine to another. This relationship can therefore essentially vary with the production of built material and slightly over time.

C_L at flight condition for a measurement point corresponds to C_D through the drag polar (quadrant (A) ; thrust is to compensate drag and is related to N1 (quadrant

(B) with the possibility of engine-to-engine model alteration (N1 (EPR) /thrust relationship).

2.7.3.2. Engine-to-engine model N1 (EPR) / thrust relationship alterations whereby DFFA – aerodynamic part – (quadrant may shift).

An observed ΔN1 or ΔEPR does not necessarily indicate an aerodynamic deterioration of the airframe. An altered N1 /thrust or EPR / thrust relationship with respect to the reference engine is, in many cases, responsible for such a deviation. This is also valid for new engines as well. Engine test-cell-gathered N1 or EPR versus thrust ratios cannot be transmitted to cruise high Mach / high altitude conditions with an acceptable confidence level.

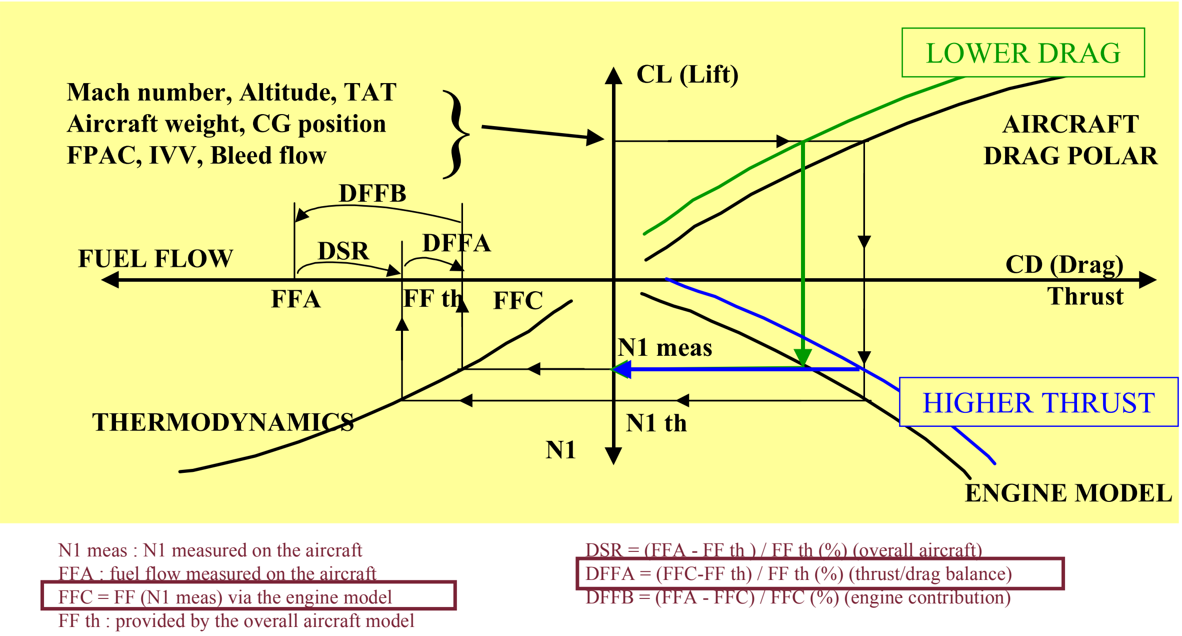


Figure D4 – Illustration of the thrust at N1/EPR uncertainty

2.7.4. Processing rule

The recorded data are processed considering the following rule. If one of the mandatory parameters is missing, an average value will be taken in replacement to run the APM program, but the final result will be biased accordingly. This is particularly true for the fuel lower heating value (FLHV) or the center of gravity location.

3. HOW TO GET THE IFP & APM PROGRAMS

The APM program is part of the Performance Engineers' Package (PEP), which includes a number of performance software.
The package is available for all Airbus aircraft types and can be customized depending on individual needs.

It can run on many computer platforms to satisfy the airlines' particular needs. These platforms are:

- Personal computers equipped with Microsoft Windows©
- Mainframes (IBM-MVS/VM systems…)
- Unix workstations

The PEP is a software mostly used by airlines' Engineering and/or Flight Operations. Airbus Flight Operations & Line Assistance department is responsible for the dispatch and the maintenance of this software. The contact address for this is:

AIRBUS

CUSTOMER SERVICES DIRECTORATE
Flight Operations & Line Assistance - STL
1, rond point Maurice Bellonte
BP33
31707 BLAGNAC Cedex
FRANCE

Fax : + 33 (0) 5 61 93 29 68/44 65
TELEX : AIRBU 530526 F

E. RESULTS APPRAISAL

1. INTRODUCTION

This chapter deals with the way to relate the results of the cruise performance analysis to a practical interpretation and gives hints at understanding where the apparent deterioration that is measured on an aircraft may come from and, in some cases, gives recommendations to actually improve the aircraft's condition.

The following is focusing on results obtained with the APM program. The pre-requisite for this chapter is a good knowledge of the APM program and of the output data that it can produce. More details on that subject are given in Chapter *D-Cruise performance analysis*.

As a reminder, the APM output data are:
- DSR represents aircraft performance degradation (in %), in terms of Specific Range degradation.
- DFFBx is the deviation of fuel flow due to the engine deterioration (engine number x).
- DFFAx is the deviation of fuel flow due to the "apparent" airframe deterioration (DFFAx is equivalent to a delta of drag) linked to engine number x.
- DN1x (resp. DEPRx) is the deviation of N1 (resp. EPR) for engine number x to maintain flight conditions.

2. INTERPRETING THE APM OUTPUT DATA

As a reminder, the purpose of the APM program is to compare the actual aircraft performance level versus the book level. The following lines give the possible conclusions when interpreting the output data.

Figure E1 reminds the APM principle.

APM principle

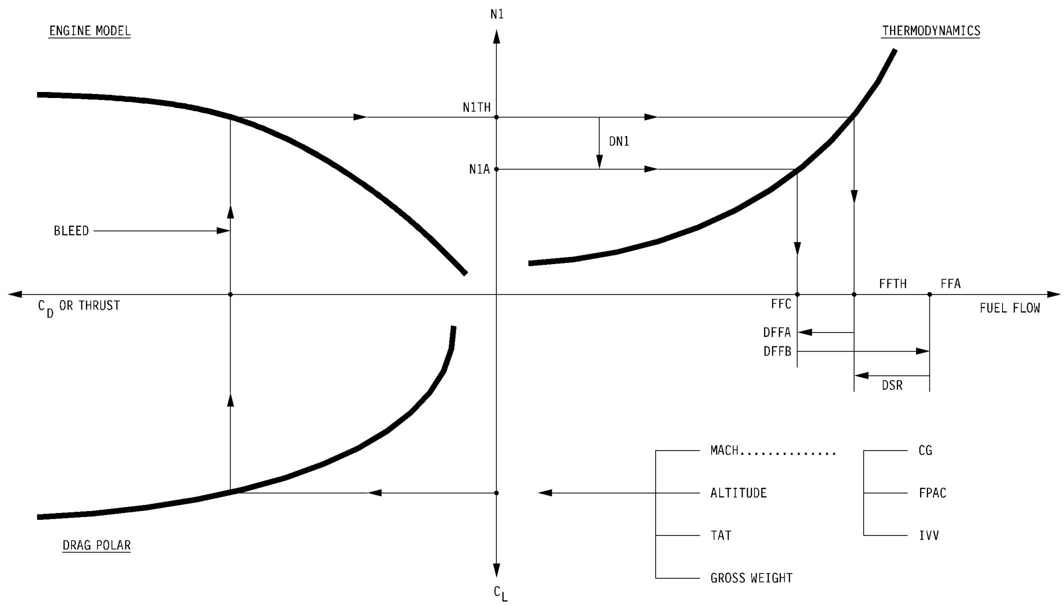


Figure E1 - APM principle

The above figure proves that a positive N1/EPR deviation results in a positive DFFA.

2.1. DFFA interpretation

Case 1 - $DN1_1$ and $DN1_2$ >0 and thus $DFFA_1$ and $DFFA_2$ >0
DFFA> 0, i.e. higher apparent drag or lower thrust at N_1than model

Case 2 - DN_{11} and DN_{12} <0 and thus $DFFA_1$ and $DFFA_2$<0
DFFA<0 i.e. lower apparent drag (or higher thrust at N_1) than model

2.2. DFFB interpretation

Case 1 - $DFFB_1$ and/or $DFFB_2$>0
higher fuel consumption than model

Case 2 - $DFFB_1$ and/or $DFFB_2$< 0
lower fuel consumption than model

Case 3 - $DFFB_1$ >0 and$DFFB_2$<0
$|DFFB_1| > |DFFB_2| \Rightarrow$ DFFB > 0: higher consumption from engine part
$|DFFB_1| < |DFFB_2| \Rightarrow$ DFFB < 0: lower consumption from engine part

Case 4 - DFFB1 < 0 and DFFB2> 0
$|DFFB_1| > |DFFB_2| \Rightarrow$ DFFB < 0: lower consumption from engine part
$|DFFB_1| < |DFFB_2| \Rightarrow$ DFFB >0: higher consumption from engine part

2.3. DSR interpretation

Combining paragraphs 2.1 and 2.2 gives the following possibilities with regard to specific range deviation.

Case 1 - DFFA > 0 and DFFB > 0 ⇒ DSR < 0
Compounded effect resulting in specific range deviation (worse than book value)

Case 2 - DFFA < 0 and DFFB > 0

1) if | DFFA | > | DFFB | ⇒ DSR > 0
Higher engine fuel consumption than model is being compensated by an apparently better than nominal aerodynamic condition resulting in better specific range than book value

2) if | DFFA| < | DFFB| ⇒ DSR < 0
Partial compensation of resulting in worse specific range than book value

Case 3 - DFFA > 0 and DFFB < 0:

1) If | DFFA | < | DFFB | ⇒ DSR < 0
Partial compensation of resulting in worse specific range than book value

2) if | DFFA | < | DFFB | ⇒ DSR > 0
An apparently worse than nominal aerodynamic condition is being compensated by lower engine consumption than model, resulting in better specific range than book value.

Case 4 - DFFA < 0 and DFFB < 0 ⇒ DSR > 0
Compounded effect resulting in specific range deviation (better than book value)

3. EXAMPLE

This paragraph is based on a cruise performance analysis that was performed for an A310-304 fitted with CF6-80C2A2 in year 1990.

Figure E2 shows manual readings that were taken at that time. The three stable points identified from the manual recordings of Figure E2 were processed by APM. Only two of these were retained by the statistical procedure and are framed in Figure E3.

The result of DFFA and DFFB (with DFFA < 0 and DFFB > 0 and DFFA < DFFB) is a marginal deviation in DSR (-0.56%). Higher engine fuel consumption than model is very often observed and at times is partially compensated by an apparently better than nominal aerodynamic condition as exemplified in the APM outputs shown in Figure E3.

Averages for the three frames

I

EGT	638/626	N - air conditioning	
ALT	36879/36787	CG	= 36.4
MACH	.801/.807	FPAC	= - 0.00044
SAT/TAT	-56.2/-28.2	V.V.	= - 0.4
N_{11}/N_{12}	90.18/90.08	WLV - trimming	
ff_1/ff_2	2081/2069		
FU	21962	GW_1	= 118.757

II

EGT	638/626	N - air conditioning	
ALT	36977/36987	CG	= 36.4
MACH	.798/.803	FPAC	= - 0.00022
SAT/TAT	-56.7/-29	V.V.	= - 0.4
N_{11}/N_{12}	90.2/90.1	WLV-trimming	
ff_1/ff_2	2080/2065		
FU	22107	GW_1	= 118.612

III

EGT	638/627	N - air conditioning	
ALT	36977/36987	CG	= 36.4
MACH	.796/.801	FPAC	= + 0.00044
SAT/TAT	-56/-25	V.V.	= - 0.4
N_{11}/N_{12}	90.23/90.13	WLV - trimming	
ff_1/ff_2	2080/2068		
FU	22172	GW_1	= 118.747

Figure E2 - Example of manual recordings

```
*** A I R B U S   C R U I S E   P E R F O R M A N C E * A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G (APM) ***
------------------------------------------------------------------------------------------------------------------------------
                                         *** PROGRAM : APMPC 11.2 ***

*** ENGINE SER.NO. L :            *** DATA BASE :                                                                       ***
*** ENGINE SER.NO. R :                AERO    A310-304    FROM  28/02/87  / GENERAL A310-304-01  FROM  30/03/86         ***
*** TAIL-NUMBER :                     ENGINE  A310-304    FROM  25/04/90    TYPE      CF6-80C2A2                        ***
```

NO	DATE	FLNO	CASE	ALT	TAT	MACH	WEIGHT	CG	FPAC	VV	THDG	LAT	VWI	DWI	ACT. W.
				FEET	C		KG	%	G	FT/MIN	DEG	DEG	KTS	DEG	N
1	210690	303	1	37040.	-29.7	.806	121909.	36.1	.0000	1.2	----	----	----	----	1195519.
2	210690	303	2	37041.	-29.7	.806	121837.	36.1	.0000	1.2	----	----	----	----	1194813.
3	210690	303	3	37047.	-29.7	.805	121694.	36.1	.0000	1.2	----	----	----	----	1193411.
4	210690	303	4	36984.	-30.0	.803	120219.	36.6	.0004	.0	----	----	----	----	1178946.
5	210690	303	5	36984.	-29.7	.803	120147.	36.6	.0003	.0	----	----	----	----	1178240.
6	210690	303	6	36935.	-29.0	.801	119254.	36.3	.0000	.0	----	----	----	----	1169482.
7	210690	303	7	36935.	-28.7	.803	119177.	36.3	.0003	.0	----	----	----	----	1168727.
8	210690	303	8	36934.	-28.7	.803	119107.	36.3	.0002	.0	----	----	----	----	1168041.
9	210690	303	9	36933.	-28.2	.804	118757.	36.4	-.0004	-.4	----	----	----	----	1164608.
10	210690	303	11	36932.	-29.0	.799	118547.	36.4	.0004	-.4	----	----	----	----	1162549.

```
*** A I R B U S   C R U I S E   P E R F O R M A N C E * A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G (APM) ***
------------------------------------------------------------------------------------------------------------------------------
                                         *** PROGRAM : APMPC 11.2 ***

*** ENGINE SER.NO. L :            *** DATA BASE :                                                                       ***
*** ENGINE SER.NO. R :                AERO    A310-304    FROM  28/02/87  / GENERAL A310-304-01  FROM  30/03/86         ***
*** TAIL-NUMBER :                     ENGINE  A310-304    FROM  25/04/90    TYPE      CF6-80C2A2                        ***
```

NO	BL	WBL1	WBL2	N11	N12	FFA1	FFA2	FLHVR	N1TH	FFTH	FF1	FF2	DN11	DN12	DFF11	DFF12	DFF21	DFF22	DSR
		--- KG/S ---		---- % -----		--- KG/H ---			%	------ KG/H -------			-------------------- % --------------------						
1	N	----	----	90.6	90.5	2122.	2114.	.999	91.1	2117.	2077.	2069.	-.44	-.54	-1.85	-2.27	2.14	2.19	-.07
2	N	----	----	90.6	90.5	2122.	2112.	.999	91.1	2118.	2077.	2068.	-.47	-.57	-1.95	-2.37	2.18	2.14	.04
3	N	----	----	90.7	90.6	2127.	2115.	.999	91.0	2110.	2079.	2071.	-.36	-.44	-1.50	-1.84	2.33	2.10	-.51
4	N	----	----	90.1	90.1	2081.	2086.	.999	90.6	2082.	2033.	2033.	-.55	-.55	-2.35	-2.35	2.36	2.61	-.08
5	N	----	----	90.2	90.2	2087.	2089.	.999	90.6	2079.	2038.	2038.	-.47	-.47	-2.01	-2.01	2.43	2.53	-.41
6	N	----	----	90.2	90.1	2081.	2066.	.999	90.4	2050.	2030.	2024.	-.23	-.30	-.98	-1.26	2.51	2.06	-1.13
7	N	----	----	90.2	90.1	2081.	2066.	.999	90.6	2067.	2034.	2026.	-.38	-.48	-1.61	-2.01	2.32	1.99	-.30
8	N	----	----	90.2	90.1	2081.	2066.	.999	90.6	2069.	2038.	2030.	-.35	-.45	-1.47	-1.87	2.10	1.78	-.23
9	N	----	----	90.2	90.1	2081.	2069.	.999	90.4	2046.	2030.	2022.	-.19	-.29	-.79	-1.19	2.51	2.34	-1.39
10	N	----	----	90.2	90.1	2080.	2068.	.999	90.3	2043.	2032.	2024.	-.12	-.22	-.51	-.92	2.35	2.18	-1.51
									MEAN VALUE				-.36	-.43	-1.50	-1.81	2.33	2.19	-.56
									STANDARD DEVIATION				.14	.12	.58	.51	.14	.25	.57

```
*** 95 % CONFIDENCE :
    THE 5% VALUES OUT OF RANGE (MEAN+- 2*SIGMA) ARE SET TO "*" AND ARE NOT INCLUDED IN THE FINAL MEAN VALUE AND STANDARD DEVIATION

*** A I R B U S   C R U I S E   P E R F O R M A N C E * A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G (APM) ***
------------------------------------------------------------------------------------------------------------------------------
                                         *** PROGRAM : APMPC 11.2 ***

*** ENGINE SER.NO. L :            *** DATA BASE :                                                                       ***
*** ENGINE SER.NO. R :                AERO    A310-304    FROM  28/02/87  / GENERAL A310-304-01  FROM  30/03/86         ***
*** TAIL-NUMBER :                     ENGINE  A310-304    FROM  25/04/90    TYPE      CF6-80C2A2                        ***
```

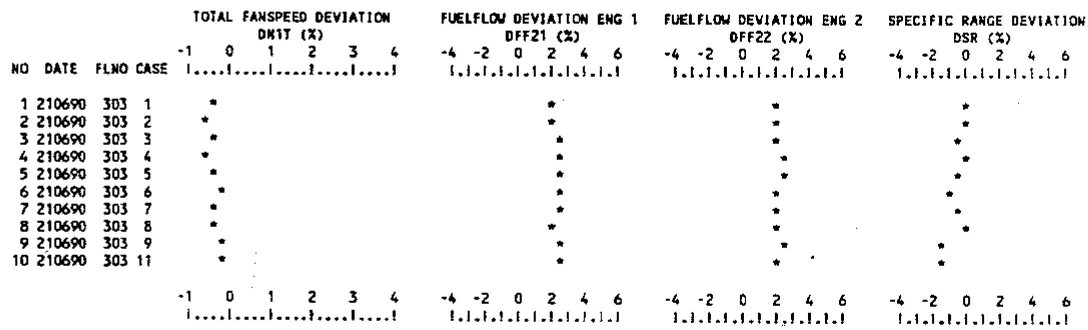


Figure E3 - Example of APM output

4. REMARKS

A few remarks are given below, based on the feedback Airbus has had from the operators. Any suggestion or comment on this part is welcome. These remarks apply to both manual and automatic readings.

These remarks have been classified depending on their theme.

4.1. Correlating measured deviations to the aircraft

1. Up to now, engine modular analysis has been barely capable of supporting aircraft performance monitoring with respect to distinguishing airframe and engine contributors to performance deviations. Yet, this type of analysis should be quite consistent with the APM analysis (DFFB parameter) in terms of trending. Indeed, the APM / IFP (global aircraft performance) of Airbus and in the Engine Condition Monitoring (engine performance) provided by the engine manufacturer use consistent engine models. As a consequence, the trends observed with both tools should be consistent with each other.

2. A suspected airframe deterioration resulting from an observed ∆N1 or ∆EPR should be confirmed by verified (visible) aerodynamic drag / airflow disturbance sources such as misrigging, dents, missing seals, steps, gaps, etc.

3. Therefore, conduct a visual inspection (extended walk around) of the aircraft noting any possible aerodynamic discrepancies and possibly confirming these by photographs. Also do this in flight, should a visual observation of the (upper) wing surfaces be performed (slats, spoilers, flap, ailerons) and pictures be taken (zoom photographs).

4. For A300/A310 Aircraft asymmetry drag diagnosis can be performed using the Zero Control Wheel technique (FCOM 2.02.09 for A310 / A300-600).

4.2. Practical aspects

1. The Specific Range (SR) method is the most effective procedure to be used in airline practice, but crew additional considerations may pre-empt its use. Indeed, the statistical approach in the specific range method makes the measured delta specific range fluctuates. This analysis could be cross-checked via other means (like periodic flight crew reporting) in order to assess the measured fuel factor. More details on this subject is given in Chapter *G-Policy for updating the Fuel Factor*.

2. When performing manual reading, parallel AIDS or ACMS analysis may be performed for back-to-back comparisons, if the event marker is activated every minute or if the printer can be used in conjunction with manual recordings.

3. Data trends should be tracked when assessing APM outputs, as illustrated in Chapter *G-Policy for updating the Fuel Factor*.

4. As a reminder, the analysis performed with the Airbus tools is based on aircraft models or databases called IFP databases or High Speed Performance databases. These databases are valid for cruise analysis in the expected usual operational conditions. Should not-expected conditions be encountered, the cruise performance analysis could be biased due to an aircraft database effect. For instance, points recorded below 20000 feet (it sometimes occurs even though the systems for automatic retrieval are configured not to record such points), should be disregarded. However a range of altitudes above 20000 ft should be recorded to have a spectrum of different wing loading (W/δ) so as to assess the consistency of any positive or negative SR deviation.

LEFT INTENTIONALLY BLANK

F. USING THE MONITORED FUEL FACTOR

1. INTRODUCTION

Airline Flight Planning systems are based on a reference aircraft performance level (book level or IFP level, see paragraph *A-1. The book level*). In order to establish a fuel policy, an adjustment of this level is required by most of the regulations (e.g. JAR-OPS) in order to get scheduled flight planning consistent with the actual aircraft performance level.

Furthermore, airlines flight operations are usually in charge of performing route studies both for operational and commercial purposes. These studies are usually conducted with the Airbus high speed performance calculation software. This software allows to get aircraft performance relevant for the book level. As a consequence, tuning the different fuel studies by means of the monitored fuel factor is mandatory for day-to-day flight operations.

On the other hand, the FMS onboard the aircraft also performs fuel consumption predictions based on a reference model: the FMS performance database. The PERF FACTOR entered in the MCDU helps to the FMS predictions.

Implementing aircraft performance monitoring aims to determine the monitored fuel factor. The intent of this paragraph is to correlate the factors required in the various fields of application on one hand with the monitored fuel factor on the other.

In the following, the term "fuel factor" will be applied to both mathematically factor (ie the modified fuel flow is the reference fuel flow times the fuel factor) or arithmetic deviation (in percent, ie the modified fuel flow is the reference fuel flow, times the fuel factor plus 1). The same terminology will be used and the symbol % will be added to deviations in percentage.

2. FMS PERF FACTOR

2.1. Purpose

The intent of this paragraph is to explain how to tune the FMGEC/FMC fuel predictions using the PERF FACTOR. It mostly synthesizes the contents of the Flight Crew Operating Manual focusing on the FMS PERF FACTOR.
Should a discrepancy be noticed between the following and the FCOM, the latter prevails.

This concerns the following FMS manufacturers:

<table>
<tr><th>Aircraft type</th><th>Manufacturer</th><th>Generic name</th><th>Other designation</th></tr>
<tr><td rowspan="2">A300-600/A310</td><td>Smith</td><td rowspan="2">FMS</td><td>-</td></tr>
<tr><td>Honeywell (Sperry)</td><td>-</td></tr>
<tr><td rowspan="3">A320 Family
A330/A340</td><td>Honeywell</td><td>FMS1</td><td>Honeywell FMS Legacy</td></tr>
<tr><td>Honeywell</td><td>FMS2</td><td>Honeywell FMS Pegasus</td></tr>
<tr><td>Thales</td><td>FMS2</td><td>-</td></tr>
</table>

2.2. FMS Perf Data Base (PDB)

The main FMS aircraft performance predictions deal with:
- fuel consumption, time,
- climb and descent path,
- recommended maximum altitude, and
- optimization of speeds and cruise altitude taking into account economic criteria defined by the airline Cost Index.

The PDB is derived from the IFP aircraft databases, which is consistent with the book level (see also *A-1. The book level*). Slight simplifications were taken into account because of the limited size of the FMS memory. For example, only one air conditioning setting is available (LO/ECON as appropriate).

The FMGEC/FMC contains an integrated aircraft performance database. This database is used by the FM part of the FMGEC/FMC to compute the predictions. The airlines cannot modify any data in the aircraft performance database. Fuel predictions can be adjusted by using a PERF FACTOR (see below) or an IDLE FACTOR (A330/A340 only).
Per design, the aircraft performance databases are stored in the FMS Perf Data Base (PDB). There is only a single PDB per family of aircraft. The activation of the right model in the PDB is done when the FMGEC/FMC is installed on the aircraft by a pin program setting.

The corresponding aircraft model identification is then displayed on the MCDU A/C STATUS page.

2.3. Update of the PDB

For aircraft not fitted with FMS2, the FMS PDB is part of the FM hardware. Update of the Perf Data Base can be done, on current FMS, only at the opportunity of a new FMGEC standard certification.

For aircraft fitted with FMS2, the FMS PDB is part of the FM software. Its update is subject to a Service Bulletin and installation of a new PDB part number.

2.4. PERF FACTOR definition

2.4.1. General

The FMS PERF FACTOR is used for fuel prediction computation within the Flight Management part of the FMGS. The PERF FACTOR is a positive or negative percentage that is used to tune the predicted fuel flow used for fuel prediction computation. In other words, the PERF FACTOR is used to adjust the FMS aircraft performance level to the actual aircraft performance capability.

The predicted fuel flow is modified according to the following formula:

$$FF_{PRED} = FF_{MODEL} \times \left(1 + \frac{\text{PERF FACTOR}(\%)}{100}\right)$$

where
- FF_{PRED} is the fuel flow used for prediction
- FF_{MODEL} is the fuel flow out of the FMS aircraft performance database
- PERF FACTOR(%) is the performance factor entered in the MCDU in percent

This correction is applied throughout the flight.

The PERF FACTOR can only be entered/modified on ground. It is entered in the AIRCRAFT STATUS page, like any other data. Read paragraph *0-2.6. Procedure to change the PERF FACTOR*.

The PERF FACTOR is the sum of two different factors:
- The basic FMS PERF FACTOR
- The monitored fuel factor, using an aircraft performance monitoring method (read chapter *B-3 The cruise performance analysis methods*)

In the following, the FMS performance factor will be referred to as FMS PERF FACTOR or PERF FACTOR.

2.4.2. Basic FMS PERF FACTOR

As a reminder, the nominal performance level of the aircraft is what we call the IFP level or book level (read paragraph *D-1.The book level* for more details). There is one IFP level per aircraft model. Several aircraft models may have the same IFP level if they strictly have the same in-flight performance.

On the other hand, the size of the FMS performance database is not sufficient to contain all the different aircraft performance models. Depending on the aircraft/engine combination, the FMS performance model may not be exactly the one of the aircraft on which it is installed. As a consequence, the engine type that is displayed on A/C STATUS page may not correspond to the installed one.

Therefore, a correction should be applied when the aircraft FMS database does not exactly fit to the aircraft model. It results in FMS predictions consistent with the aircraft book level.

2.4.3. Monitored fuel factor

On the other hand, the actual aircraft drag and engine performance deviate from the nominal model due to the aircraft's aging process. Applying a correction will shift the performance level from the book level to the actual performance level enabling better fuel predictions.
As a reminder, the monitored fuel factor can be obtained from one of the aircraft performance monitoring methods.

In the absence of measurements, the monitored fuel factor makes a default assumption in terms of fuel quality. Basically, FMS predictions are performed with a basic FLHV equal to 18400 BTU/LB (which is very conservative). As of a consequence, and in order not to over-penalize the FMS prediction, the monitored fuel factor should be corrected for the FLHV effect.

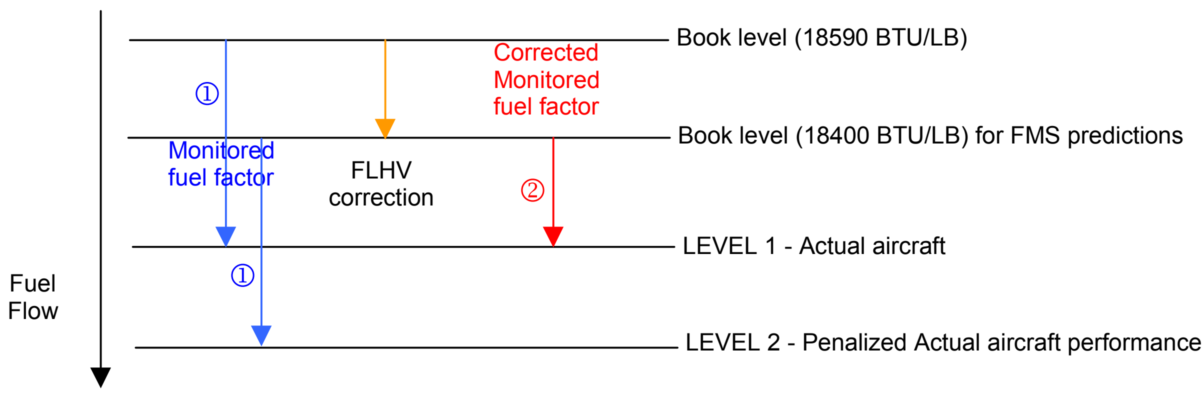


Figure F1 - Effect of the FLHV on the monitored fuel factor for the FMS predictions

The arrows “①” represent the monitored fuel factor, based on a 18590 BTU/LB. If this monitored fuel factor is entered in the MCDU, the fuel predictions will be consistent with LEVEL 2 (see figure F1). FMS predictions will be hence somewhat penalized. Correcting the monitored fuel factor (arrow “②”) ensures the FMS predictions are consistent with LEVEL 1 (see figure F1).

For example, if:

1. the cruise performance analysis is performed with a FLHV equal to 18590 BTU/LB, and
2. the monitored fuel factor is equal to 2%

Keeping in mind the FMS predictions are based on a 18400-FLHV, the corrected monitored fuel factor is equal to the monitored fuel factor corrected for the FLHV effect, that is to say:

$$2.0\% - \left(1 - \frac{18400}{18590}\right) \times 100 \approx 0.98\% \approx 1.0\%$$

2.4.4. FMS PERF FACTOR

The FMS PERF FACTOR must be entered in the aircraft MCDU on the A/C STATUS page. The PERF FACTOR for the FMS predictions is the sum of the basic PERF FACTOR (in percent) and the monitored fuel burn deviation (in percent).

2.5. Basic FMS PERF FACTOR

On A300-600/A310 aircraft and fly-by-wire aircraft fitted with FMS1, the default PERF FACTOR is defined in the hardware and is equal to 0.0.

On aircraft fitted with FMS2, the default PERF FACTOR is either 0.0 (hardware) or is defined in the FMS Airline Modifiable Information (AMI) file, also called FM airline configuration file. The basic value defined in the AMI file corresponds to 1.0. For more information on that subject, read Flight Crew Operating Manual (FCOM), section 1.22.10 P2.

Of course, the PERF FACTOR that is entered in the MCDU overrides the default value.

This paragraph details the basic FMS PERF FACTOR to be considered when updating the FMS PERF FACTOR. The following figures are given in percentage.

2.5.1. General assumptions

All these factors were determined with the following hypotheses:

- Anti-Ice OFF
- FLHV: 18400 BTU/LB
- Air conditioning:
  - NORM for A319, A320 (except A320 CFM fitted with FMS2), A321, A340 with FMS1
  - LO/ECON for A320 CFM fitted with FMS2, A330, A340 with FMS2

Note: The FMS performance databases are based on a default Fuel Lower Heating Value (FLHV, see also paragraph "B-3.4.3.1.Fuel Lower Heating Value (Fuel LHV)") set to 18400 BTU/LB. So, when FLHV goes up from 18400 BTU/LB to 18590 BTU/LB, it is necessary to reset the performance factor values to –1.0%.

2.5.2. A300-600/A310 aircraft

The basic PERF FACTOR entered in the MCDU at delivery is "0.0" for all A300-600/A310 aircraft.

2.5.3. A320 "CFM" engines

The "CFM" family is split into several tables due to the numerous versions on aircraft fitted with CFM56-5B engines. Indeed, this engine type (5B) enables to have **SAC** (Single Annular Combustion chamber) or **DAC** (Double Annular Combustion chamber) and the "**/P**" option, which is a SFC (Specific Fuel Consumption) improvement ("physically" resulting from a HP blade and LP compressor modification).

For all these aircraft the basic performance factor is given below.

2.5.3.1. CFM56-5A engines

2.5.3.1.1. FMS1

		Perf Factor
A319-113	CFM56-5A4	0.0
A319-114	CFM56-5A5	0.0
A320-111	CFM56-5A1	0.0
A320-211	CFM56-5A1	+0.5
A320-212	CFM56-5A3	+0.5

2.5.3.1.2. FMS2

		Perf Factor
A319-113	CFM56-5A4	0.0
A319-114	CFM56-5A5	0.0
A320-111	CFM56-5A1	0.0
A320-211	CFM56-5A1	0.0
A320-212	CFM56-5A3	0.0

2.5.3.2. CFM56-5B engines

2.5.3.2.1. FMS1

		Non /P		/P	
		SAC	DAC	SAC	DAC
A319-111	CFM56-5B5	0.0	0.0	-4.5	-3.5
A319-112	CFM56-5B6	0.0	0.0	-4.5	-3.5
A319-115	CFM56-5B7	0.0	0.0	-4.5	-3.5
A320-214	CFM56-5B4	0.0	0.0	-3.0	-2.0
A321-111	CFM56-5B1	0.0	0.0	-2.0	-1.5
A321-112	CFM56-5B2	0.0	0.0	-2.0	-1.5
A321-211	CFM56-5B3	0.0	0.0	-2.0	-1.5
A321-212	CFM56-5B1	0.0	0.0	-2.0	-1.5
A321-213	CFM56-5B2	0.0	0.0	-2.0	-1.5

2.5.3.2.2. FMS2

		Non /P		/P	
		SAC	DAC	SAC	DAC
A319-111	CFM56-5B5	4.5	4.5	0.0	1.0
A319-112	CFM56-5B6	4.5	4.5	0.0	1.0
A319-115	CFM56-5B7	4.5	4.5	0.0	1.0
A320-214	CFM56-5B4	3.0	3.0	0.0	1.0
A321-111	CFM56-5B1	2.0	2.0	0.0	1.0
A321-112	CFM56-5B2	2.0	2.0	0.0	1.0
A321-211	CFM56-5B3	2.0	2.0	0.0	1.0
A321-212	CFM56-5B1	2.0	2.0	0.0	1.0
A321-213	CFM56-5B2	2.0	2.0	0.0	1.0

2.5.4. A320 “IAE” family :

2.5.4.1. FMS1

		Perf Factor
A319-131	V2522-A5	–0.5
A319-132	V2524-A5	–0.5
A319-133	V2527M-A5	–0.5
A320-231	V2500-A1	0.0
A320-232	V2527-A5	+0.5
A320-233	V2527E-A5	+0.5
A321-131	V2530-A5	-0.5
A321-231	V2533-A5	-0.5
A321-232	V2530-A5	-0.5

2.5.4.2. FMS2

		Perf Factor
A319-131	V2522-A5	0.0
A319-132	V2524-A5	0.0
A319-133	V2527M-A5	0.0
A320-231	V2500-A1	0.0
A320-232	V2527-A5	0.0
A320-233	V2527E-A5	0.0
A321-131	V2530-A5	0.0
A321-231	V2533-A5	0.0
A321-232	V2533-A5	0.0

2.5.5. A330 aircraft

2.5.5.1. FMS1

		Perf Factor
A330-202	CF6-80E1A2	-1.0
A330-223	PW4168A	-1.0
A330-243	TRENT772B-60	-3.0
A330-301	CF6-80E1A2	0.0
A330-321	PW4164	0.0
A330-322	PW4168	0.0
A330-323	PW4168A	0.0
A330-341	TRENT768-60	0.0
A330-342	TRENT772-60 OH (*1)	0.0
A330-342	TRENT772-60 NH (*1)	-2.0
A330-343	TRENT772B-60	-2.0

(*1) : **OH**: Old Hardware, before Engine Serial Number 41054.
NH: New Hardware, since Engine Serial Number 41054.

2.5.5.2. FMS2

		Perf Factor
A330-201	CF6-80E1A2	-1.0
A330-202	CF6-80E1A4	-1.0
A330-203	CF6-80E1A3	-1.0
A330-223	PW4168A	-1.0
A330-243	TRENT772B-60	-1.0
A330-301	CF6-80E1A2	0.0
A330-302	CF6-80E1A4	0.0
A330-303	CF6-80E1A3	0.0
A330-321	PW4164	0.0
A330-322	PW4168	0.0
A330-323	PW4168A	0.0
A330-324	PW4173	0.0
A330-341	TRENT768-60	0.0
A330-342	TRENT772-60 OH (*1)	0.0
A330-342	TRENT772-60 NH (*1)	-2.0
A330-343	TRENT772B-60	-2.0

(*1) : **OH**: Old Hardware, before Engine Serial Number 41054;
NH: New Hardware, since Engine Serial Number 41054.

2.5.6. A340 aircraft

2.5.6.1. FMS1

		Perf Factor
A340-211	CFM56-5C2	-1.5
A340-212	CFM56-5C3	-3.0
A340-213	CFM56-5C4	-2.0
A340-311	CFM56-5C2	-1.5
A340-312	CFM56-5C3	-1.5
A340-313	CFM56-5C4	-0.5
A340-313E	CFM56-5C4	0.0

2.5.6.2. FMS2

		Perf Factor
A340-211	CFM56-5C2	-2.0
A340-212	CFM56-5C3	-2.5
A340-213	CFM56-5C4	-1.0
A340-213E	CFM56-5C4	0.0
A340-311	CFM56-5C2	0.0
A340-312	CFM56-5C3	-1.0
A340-313	CFM56-5C4	0.0
A340-313E	CFM56-5C4	0.0
A340-642	TRENT 556	+ 0.5 %

2.6. Procedure to change the PERF FACTOR

The PERF FACTOR should be regularly updated based on the routine aircraft performance monitoring. This paragraph details the procedure to change the PERF FACTOR in the CDU/MCDU.

Airbus recommends that only authorized and qualified staff members perform this procedure. The crew should not change the value by themselves.

The PERF FACTOR can only be modified on ground.

Note: On fly-by-wire aircraft, the PERF FACTOR is displayed in CYAN when on ground (modifiable) and in GREEN when airborne or when no change code was entered (not modifiable). It is displayed in large blue font, following a modification.

2.6.1. A300-600/A310 aircraft

1. Select the CDU A/C STATUS page
2. Type the new value
3. Press LSK 6L.

2.6.2. A320 Family aircraft

2.6.2.1. Aircraft fitted with FMS1

1. Select the MCDU A/C STATUS page
2. Type the new value
3. Press LSK 6R. The new value is displayed in large fonts (CYAN on the ground, GREEN in-flight)

2.6.2.2. Aircraft fitted with FMS2

If no PERF FACTOR was entered, the Airline Modifiable Information (AMI) values are taken into account and are displayed in small font. Changing the PERF FACTOR value thanks to the below procedure will over-ride the PERF FACTOR value that is defined in the AMI.

Following steps describe how to change the PERF FACTOR value:
1. Enter "ARM" in the CHG CODE line [5L]brackets (or appropriate password)
2. Write the new IDLE/PERF factor in the scratchpad
3. Enter this new factor in line [6L]. The entered factor is displayed in large CYAN font.

The airline may change the ARM code by modifying the NAV DATA BASE policy file.

2.6.3. A330/A340 aircraft

On the MCDU A/C STATUS page:

1. Enter ARM into brackets in the CHG CODE line [5L]
2. Write the new IDLE/PERF factors
3. Insert the new factor using [6L] key. A manually entered IDLE/PERF factor is displayed in large CYAN fonts.

2.7. Effects of the PERF FACTOR

Adjusting the PERF FACTOR has an impact on fuel flow predictions. As of a consequence, comparing the scheduled fuel consumption with or without defining a PERF FACTOR will exhibit noticeable differences. The purpose of this paragraph is to succinctly describe the influence of the PERF FACTOR.

First, PERF FACTOR is an FMS internal correction. It is not sent to any other computer linked to the FMS (FADEC, EIU…).

Second, as defined above, the PERF FACTOR basically modifies the FMS predicted fuel flow. Hence, it impacts the items listed below.

2.7.1. Estimated fuel on board (EFOB) and estimated landing weight

The EFOB is calculated based on integration of the predicted fuel flow over time. Thus, the PERF FACTOR has an influence of the EFOB displayed on both MCDU PERF and F-PLN pages.

Also, the estimated landing weight is calculated taking into account the zero fuel weight (ZFW) entered in the MCDU and the EFOB at destination. Consequently, the PERF FACTOR has also an impact on the estimated landing weight at destination.

2.7.2. ECON speed/Mach number

The ECON speeds are calculated so as to minimize the cost function. The cost function depends on the predicted fuel flow or predicted specific range, on the Cost Index entered in the MCDU and on the ground speed.

The PERF FACTOR therefore has an influence on the predicted ECON speeds. The Cost Index used for ECON speeds computation is modified according to the following formula:

$$\boxed{CI_{PF} = \frac{CI}{1 + \frac{PERF\ FACTOR}{100}}}$$

where CI is the Cost Index entered in the MCDU
CI_{PF} is the corrected Cost Index for the PERF FACTOR
PERF FACTOR is the factor entered in the MCDU

Yet, the influence of the PERF FACTOR is quite small. The highest deviations are generally observed at high gross weights. The effect is more significant on A330/A340 aircraft types.

As a general rule, the higher the PERF FACTOR, the lower the ECON speeds.

2.7.3. Characteristic speeds

The FMS computes flight characteristic speeds and displays the predicted values in the MCDU PERF pages. As a reminder, the characteristic speeds are F, S and O speeds during the T/O and APPR phases, VLS and VAPP CONF3 and CONF FULL during the APPR phase.

The characteristic speeds are calculated based on the predicted aircraft gross weight, which is the sum of the zero fuel weight (ZFW) and the estimated fuel on board (EFOB).

As the PERF FACTOR modifies the EFOB, it also impacts characteristic speeds.

The higher the PERF FACTOR, the lower the EFOB, the lower the characteristic speeds.

2.7.4. Recommended Maximum altitude (REC MAX ALT)

The FMS RECommended MAXimum ALTitude (REC MAX ALT) is defined as the altitude, which can be:
- flown with a speed higher than GREEN DOT and lower than VMO/MMO,
- reached with a minimum vertical speed of 300ft/mn at Max climb thrust,

- flown in level flight without acceleration with an engine rating less than Max cruise,
- reached before buffeting (the margin depends on the aircraft models, 0.3g for fly-by-wire aircraft)

It is displayed on the MCDU PROG page.

The REC MAX ALT is less than or equal to the CERtified MAXimum ALTitude as provided in the Airplane Flight Manual (AFM). This calculation is permanently updated during flight.

The REC MAX ALT is a pre-computed value function of the aircraft gross weight and the ISA deviation (the ISA model is defined in the FMGEC thanks to the temperature and the tropopause altitude that are entered in the MCDU).

As a consequence, the PERF FACTOR has no influence on the REC MAX ALT.

2.7.5. Optimum altitude (OPT ALT)

The Optimum Altitude function is defined as the altitude at which the cost, - and at the optimum speed, - at its minimum. This calculation is permanently updated during flight.

It is displayed on the MCDU PROG page.

The calculation is made taking into account: the Cost Index, the aircraft gross weight (GW), the wind model, the temperature model (International Standard Atmosphere) and the ISA deviation.

Since the PERF FACTOR modifies the fuel flow, it changes the cost function. As a consequence, the OPT ALT is also impacted.

A positive PERF FACTOR decreases the OPT ALT, all other conditions being fixed.

3. FUEL FACTOR FOR FLIGHT PLANNING SYSTEMS

During the dispatch of any aircraft, each operator must determine the fuel quantity that is required for a safe trip along the scheduled route, and reserves to cover deviations from the planned route according to locally prevailing regulations.

Each operator has his own fuel policy and tools to prepare the required flight planning. Some operators have built in-house programs. Some others subcontract this to third party specialized in that area.

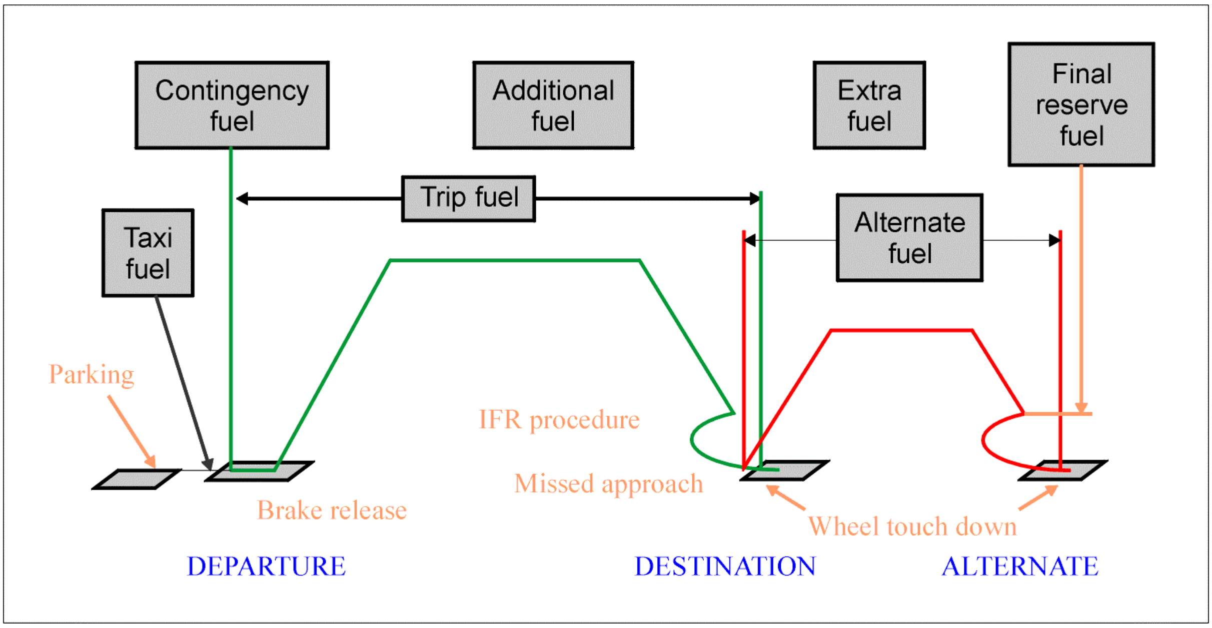
No matter which the option is chosen by the operator, all flight planning is basically based on:

- the Airbus aircraft High Speed Performance databases (IFP databases, FMS IFP databases, see paragraph *A-1.The book level*)
- The Airbus IFP program (see *0-4.Airbus Tools*)

The intent of the following lines is to clarify Airbus recommendations in term of fuel factor for flight planning preparation.

3.1. Effect of the fuel factor on Flight Planning

The following picture illustrates the different fuel quantities and associated flight phases of a typical trip.



The fuel factor defined in flight planning will modify (except fixed values of course):

- the trip fuel
- the contingency fuel (generally a percentage of the trip fuel)
- the alternate fuel
- the final reserve (holding at alternate fuel)
- the additional fuel

3.2. Keys for defining the fuel factor

Basically, the nominal performance level that is used in flight planning systems is the same as the Airbus book level (or IFP level, see *A-1.The book level)*.

This performance level may not be representative of the actual aircraft performance level. Amongst the airlines information required to feed any flight planning system, a fuel factor must be defined in accordance with the airline fuel policy (see chapter *G-Policy for updating the Fuel Factor*).

The following points must be emphasized:

1. When determining an operational flight plan at fixed speed (FMS selected or manual mode), the flight planning fuel factor must be the same as the one measured with an appropriate aircraft performance monitoring method. In other words, the fuel factor for flight planning is equal to the monitored fuel factor.

2. When determining a flight plan (or a part of it) at Cost Index ECON speeds,
   - the ECON speeds must be calculated taking into account the FMS PERF FACTOR
   - the flight plan must be calculated with the pre-calculated ECON speeds, using a method consistent with the standard IFP algorithm and taking into account the monitored fuel factor.

Note: Read paragraph 4. Airbus Tools and Fuel Factor to have more information on the capabilities of the Airbus tools covering that subject.

3. The Fuel Lower Heating Value is included within airline information pertaining to Flight Planning. The FLHV should be the same as the one used for the cruise performance analysis. If not, a correction will be applied on the monitored fuel factor.
   If the FLHV for cruise performance analysis is 1% higher than the FLHV used in the flight planning system, decrease the monitored fuel factor by 1%.

   For example, if :
   1. the cruise performance analysis is performed with a FLHV equal to 18590 BTU/LB, and
   2. the flight planning is calculated based on a FLHV equal to 18400 BTU/LB, and
   3. the monitored fuel factor is equal to 2%

   Assuming no Cost Index calculation is done, the flight planning fuel factor is equal to the monitored fuel factor corrected for the FLHV effect, that is to say:

$$2.0\% - \left(1 - \frac{18400}{18590}\right) \times 100 \approx 0.98\% \approx 1.0\%$$

4. The FMS PERF FACTOR should be indicated on the computerized flight plan so that pilots can check the computerized flight planning and FMS predictions are consistent with each other. Of course, the FMS PERF FACTOR can be different from the flight planning fuel factor determined above. But the pilots only have at hand the fuel factor that is defined for the FMS predictions, that is to say, the FMS PERF FACTOR.

3.3. Comparing FMS fuel predictions and Computerized Flight Planning

FMS fuel predictions and scheduled fuel planning indeed have different purposes. Yet, it is tempting to try to compare both fuel schedules. The intent of the following is to remind the main reasons for these differences.

As explained in this chapter, the FMS predictions are based on an FMS simplified performance database, which is different from the CFP aircraft database (consistent with the book level).

1. The fuel factors defined in the FMS (PERF FACTOR) and those destinated for flight planning computation (flight planning fuel factor) must be consistent with each other.

2. The FMS predictions may be calculated with different wind predictions than the Computerized Flight Planning (wind profile). The influence of the wind on performance is tantamont.

```
COMPUTERIZED  FLIGHT  PLANNING

PLAN XXX                      LFPO TO HECA A320   LRC/F      IFR   04/01/94
NONSTOP COMPUTED XXXXX        FOR ETD 1200Z  PROGS APR                          KGS

**************************** HISTORICAL AVERAGE WINDS HAVE BEEN USED ******************************

FLT RELEASE                   LFPO/HECA ON 04/01/94

     FLT/DAY   ORG/DEST      TTL       NAM      PRF      ROUTE      AVG WIND/AVG TEMP
       /01     LFPO/HECA               1691      F                   P030      M55

               E.FUEL     A.FUEL       E.TME    NM       NAM        FL
DEST HECA      009728     ----- ---    03/51    1800     1691       330/FRZ 370
RESV 0.05      000486     ----- ---
ALT HELX       002114     ----- ---    00/49    0296     0284       250
HOLD           001015     ----- ---    00/30
TOF            013343     ----- ---    05/10
TAXI           000140     CORR.         +/ -
BLOCK          013483     ----- ---    05/10    BLOCK FUEL -----------------------------

---------------------------------------------------------------------------------------------------

               E.WT       CORR.        OP.LIMIT          STRUC.    REASONS FOR OP.LIMIT
BASIC WT       043100     ----- ---
EPLD           013457     ----- ---
EZFW           056657     ----- ---    ZFW    ----- ---          / -----------------------------
TOF            013343     ----- ---
ETOW           070000     ----- ---    OTOW   ----- ---          / -----------------------------
EB/O           009728     ----- ---
ELAW           060272     ----- ---    LAW    ----- ---          / -----------------------------

---------------------------------------------------------------------------------------------------

WP    NAME     CO-ORDINATES                    WP    NAME     CO-ORDINATES
----  LFPO     N48 43.5   E002 22.9            ----  D247G    N48 40.8   E002 13.8
----  MOU      N46 42.4   E003 38.0            ----  MASSE    N46 24.6   E004 58.0
----  FIR      N46 12.0   E005 52.8            ----  PAS      N46 09.9   E006 00.0
----  ROCCA    N45 43.6   E006 40.5            ----  FIR      N45 30.0   E007 01.2
----  TOP      N44 55.5   E007 51.7            ----  GEN      N44 25.4   E009 05.0
----  BEROK    N44 09.9   E010 21.1            ----  FRZ      N44 01.6   E011 00.2
----  URBAN    N43 46.8   E012 25.7            ----  FIR      N43 33.6   E012 36.0
----  NORKI    N42 51.6   E013 07.4            ----  KATIG    N42 22.1   E013 58.3
----  FOG      N41 25.7   E015 31.9            ----  BAI      N41 08.0   E016 45.3
----  BRD      N40 36.6   E018 00.2            ---   TIGRA    N40 03.4   E019 00.0
----  KRK      N39 26.6   E020 04.2            ----  GARTA    N38 59.0   E020 58.0
----  ELVAS    N38 31.5   E021 50.5            ----  IXONI    N38 19.0   E022 14.0
----  KOR      N37 56.0   E022 56.0            ----  DDM      N37 28.7   E023 13.1
----  MIL      N36 44.7   E024 31.1            ----  ATLAN    N35 51.3   E025 26.2
----  SIT      N35 04.0   E026 11.7            ----  PAXIS    N33 57.1   E027 20.0
----  GESAD    N32 56.7   E028 20.0            ----  OTIKO    N31 34.3   E029 36.5
----  AXD      N31 11.2   E029 56.9            ----  MENKU    N31 05.5   E030 18.0
----  HECA     N30 07.3   E031 24.3
```

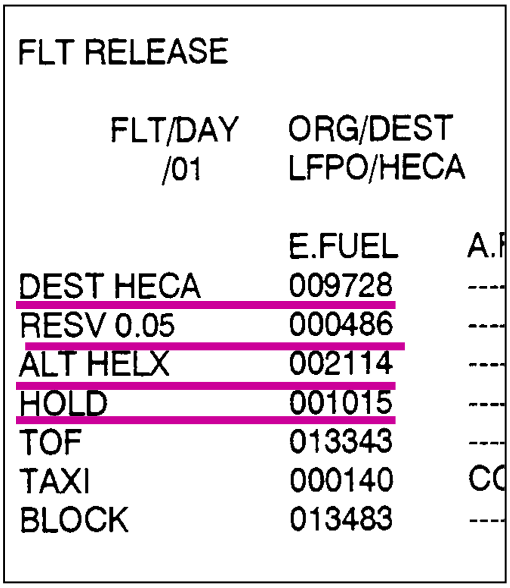
Figure F1 - Example of computerized Flight Planning

3. The flight planning computation method can induce hidden effects:
   - Some flight plannings are based on Flight Crew Operating Manual pre-calculated data. The flight plan is then calculated interpolating within FCOM data.
   - Some flight planning systems are based on pre-calculated data using the Airbus IFP program. The flight plan is then calculated interpolating within resulting data tables
   - Some other flight planning systems are based on real-condition computation, which is the most accurate method, avoiding interpolation errors

4. The ECON speeds may be determined based on an algorithm, which is not exactly consistent with the Airbus one. As of a consequence, a slight difference between scheduled ECON speeds and observed ECON speeds may occur.

5. The FMS predictions are updated in real-time, based on the actual flight profile. The Computerized Flight Planning is established at dispatch and does not include any correction for deviations from planned conditions.

Example of difference between CFP and FMS predictions
Figure F2 shows an example of predictions, for the same route, all above specified conditions being fulfilled.


FLT RELEASE

	FLT/DAY	ORG/DEST
	/01	LFPO/HECA

	E.FUEL	A.F
DEST HECA	009728	----
RESV 0.05	000486	----
ALT HELX	002114	----
HOLD	001015	----
TOF	013343	----
TAXI	000140	CC
BLOCK	013483	----

Figure F2 - Comparison CFP versus FMS predictions

Apart from the routing errors, the figures in both cases are quite consistent with each other.

4. AIRBUS TOOLS AND FUEL FACTOR

All airline Flight Operations use or at least have heard about the Airbus High Speed Performance calculation software. The intent of this paragraph is to briefly explain how to use fuel factors with these tools.

The Airbus HSP software is composed of:
- the IFP program
- the FLIP program
- the APM program

4.1. The IFP program

This paragraph describes the way to use fuel factors (monitored fuel factor, FMS PERF FACTOR) in the IFP program, depending on what is needed. For more details on the IFP functions, read *0-1.1.3. The IFP program.*

4.1.1. The IFP calculation modes

The IFP has three basic calculation modes. They are described down below.

4.1.1.1. Standard mode

Calculations performed with this mode are based on the most accurate physical model of the aircraft available (so-called the IFP model or book level), giving the most accurate fuel predictions for given speeds. Calculations are possible at economic speeds for the cruise phase only, by selecting the "optimum speed" option. But, the resulting calculations will not match up entirely with the speeds the aircraft will be adopt by means of the FMS and in equivalent conditions. These are indeed based on the optimization of the cost function using slightly different data than those stored in the FMS.

This calculation mode is based on:
- Standard IFP aerodynamic and engine database (same as book level)
- Standard IFP algorithms for data extraction and flight mechanics equations
- Standard data and algorithms for flight guidance parameters and limitations
- Adjustable atmospheric conditions
- All air conditioning settings available
- All anti ice settings available
- Adjustable FLHV
- Adjustable drag factor (modification of the aircraft drag)
- Adjustable fuel consumption factor (modification of the fuel flow)

4.1.1.2. FMS mode

Calculations performed with this mode are based on the databases stored in the FMS (FMS Perf Data Base or PDB) on the simplified equations used therein (due to the real-time constraints). For a given cost index and fuel factor, speeds given in this mode are thus the same as those flown by the aircraft in the same conditions. Fuel consumption may be slightly different from the ones actually observed, since there are some simplifications, like the assumption of low air conditioning and no anti ice whatever the actual bleed flow (see conditions below). Another restriction is that only flight conditions that can be flown under FMS managed mode are available for computation.

This calculation mode is based on:
- Simplified IFP aerodynamic and engine database (FMS aircraft performance level),
- Simplified IFP algorithms for data extraction and flight mechanics equations consistent with the ones implemented in the FMS,
- Data and algorithms for flight guidance parameters and limitations consistent with the FMS ones
- Adjustable atmospheric conditions
- LO/ECON air conditioning only, no anti-ice, as the FMS predictions
- Adjustable FLHV
- Adjustable drag factor
- Adjustable fuel consumption factor

4.1.1.3. hybrid mode (standard with FMS speeds)

This mode uses a mix of the two previous database sets in order to obtain the best of both worlds: the actual FMS speeds and accurate fuel consumption predictions under given conditions. For example, you may calculate data for any bleed setting available on the aircraft. For the flight phases being covered, this mode is ideal for flight plan performance data production. The ones not covered are usually flown in FMS selected or manual mode (single engine performance, gear down...). The FMS managed mode is equivalent to a calculation in standard mode (holding at green dot speed...).

This calculation mode is based on:
- Standard IFP aerodynamic and engine database (same as book level)
- Standard IFP algorithms for data extraction and flight mechanics equations
- Data and algorithms for flight guidance parameters and limitations consistent with the FMS ones
- Adjustable atmospheric conditions
- All air conditioning settings available
- All anti ice settings available
- Adjustable FLHV
- Adjustable drag factor
- Adjustable fuel consumption factor

4.1.2. Simulation of the FMS predictions

The intent of this paragraph is to explain how to use the IFP program to reproduce FMS predictions on board the aircraft.

4.1.2.1. Flight at given Cost Index

The IFP FMS mode should be used with the following assumptions:
1. FLHV set equal to 18400. BTU/LB (as in the on-board FMS)
2. LO/ECON air conditioning
3. Fuel Consumption Factor set equal to (1+FMS PERF FACTOR(%)/100)
4. Drag factor set equal to 1.0
5. Atmospheric conditions as close as possible to the ones used by the FMS
6. Cost Index as applicable

4.1.2.2. Flight at given speed (CAS/Mach)

This type of calculation is only possible for the CRZ and DES phases. No similar calculations can be performed for the CLB phase as the IFP FMS calculates the climb Mach depending on the Cost Index entered.

The IFP FMS mode should be used with the following assumptions:
1. FLHV set equal to 18400. BTU/LB (as in the on-board FMS)
2. LO/ECON air conditioning
3. Fuel Consumption Factor set equal to (1+FMS PERF FACTOR(%)/100)
4. Drag factor set equal to 1.0
5. Atmospheric conditions as close as possible to the ones used by the FMS
6. Speeds as applicable

4.1.3. Determination of the actual aircraft performance

The intent of this paragraph is to explain how to use the IFP program to calculate actual aircraft performance.

4.1.3.1. Flight at given Cost Index

Airbus recommendation is to use the HYBRID mode.

The HYBRID mode will perform the ECON speeds and fuel flow calculations. The fuel factor(s) have an influence on both types of items. The point is that two different fuel factor(s) must be used:
- FMS PERF FACTOR to obtain ECON speeds
- Monitored fuel factor to obtain fuel flows

In the IFP, only one consumption factor can be entered. The following gives Airbus recommendations to bypass that constraint.
The FLHV is used during the calculation of fuel flows. Basically, the higher the FLHV, the lower the fuel flow. The whole idea is to modify the FLHV by a certain amount in order to compensate for the difference between the FMS PERF FACTOR and the monitored fuel factor, that is to say, to compensate the Basic FMS PERF FACTOR.

As a general assumption, one percent FLHV deviation results in one percent deviation in fuel flow. Then,

$$\frac{FLHV_{CORR} - FLHV_{ACTUAL}}{FLHV_{ACTUAL}} = \Delta FMS\_PERF\_FACTOR(\%)$$

where $FLHV_{ACTUAL}$ is the actual FLHV
$FLHV_{CORR}$ is the corrected FLHV
ΔFMS_PERF_FACTOR(%) is the basic FMS PERF FACTOR in percent

Then,

$$FLHV_{CORR} = \Delta FMS\_PERF\_FACTOR(\%) \times FLHV_{ACTUAL} + FLHV_{ACTUAL}$$

The IFP HYBRID mode should be used with the following assumptions:
1. Corrected FLHV (see above)
2. Air conditioning/Anti Ice as appropriate
3. Fuel Consumption Factor set equal to (1+FMS PERF FACTOR(%)/100)
4. Drag factor set equal to 1.0
5. Atmospheric conditions as close as possible to the actual ones
6. Cost Index as applicable

4.1.3.2. Flight at given speed (CAS/Mach)

The IFP STANDARD mode should be used with the following assumptions:
1. FLHV as appropriate
2. Air conditioning/Anti ice as appropriate
3. Fuel Consumption Factor set equal to monitored fuel factor
4. Drag factor set equal to 1.0
5. Atmospheric conditions as close as possible to the actual ones
6. Speeds as applicable

4.2. The FLIP program

This paragraph describes the way to use the FLIP program with the different fuel factors, depending on the objective.

4.2.1. The FLIP missions

4.2.1.1. Standard Flight Planning

Calculations performed with this mode are based on the most accurate physical model of the aircraft available (so-called the IFP model), giving the most accurate fuel predictions for given speeds.

This mission is based on:
- Standard IFP aerodynamic and engine database (same as book level)
- Standard IFP algorithms for data extraction and flight mechanics equations
- Standard data and algorithms for flight guidance parameters and limitations
- Adjustable atmospheric conditions
- All Air Conditioning settings available
- All Anti Ice settings available
- Adjustable FLHV
- Adjustable thrust factor (modification of the maximum thrust/N1/EPR at a given thrust rating)
- Adjustable fuel consumption factor

4.2.1.2. FMS Flight Planning

Calculations performed with this mode are based on the databases stored in the FMS (FMS Perf Data Base or PDB) and on simplified equations used therein (due to the real-time constraints).

For a given cost index and fuel factor, speeds given in this mode are thus the same as those flown by the aircraft in identical conditions. The fuel consumption may be slightly different from the ones actually observed, since there are some simplifications, like the assumption of low air conditioning and no anti ice whatever the actual bleed flow. Another restriction: only flight conditions that can be flown under FMS managed mode by the crew are available for computation.

This calculation mode is based on:

- Simplified IFP aerodynamic and engine database (FMS aircraft performance level)
- Simplified IFP algorithms for data extraction and flight mechanics equations consistent with the ones implemented in the FMS
- Data and algorithms for flight guidance parameters and limitations consistent with the FMS ones
- Adjustable atmospheric conditions
- LO/ECON air conditioning only, no anti-ice, as the FMS predictions
- Adjustable FLHV
- Adjustable thrust factor
- Adjustable fuel consumption factor

4.2.1.3. Standard Flight Planning with FMS speeds

This mode uses a mix of the two previous database sets in order to obtain the best of both worlds: the actual FMS speeds and accurate fuel consumption predictions under given conditions. For example, you may calculate data for any bleed setting available on the aircraft. The FMS managed mode is equivalent to a calculation in standard mode.

This calculation mode is based on:

- Standard IFP aerodynamic and engine database (same as book level)
- Standard IFP algorithms for data extraction and flight mechanics equations
- Data and algorithms for flight guidance parameters and limitations consistent with the FMS ones
- Adjustable atmospheric conditions
- All air conditioning settings available
- All anti ice settings available
- Adjustable FLHV
- Adjustable thrust factor
- Adjustable fuel consumption factor

4.2.2. Simulation of FMS predictions

The intent of this paragraph is to explain how to use the FLIP program to reproduce actual FMS predictions on board the aircraft.

4.2.2.1. Flight planning at given Cost Index

The Standard Flight Planning with FMS speeds should be used with the following assumptions:

1. ECON speed selection (Managed mode)
2. FLHV set equal to 18400. BTU/LB (as in the on-board FMS)
3. LO/ECON air conditioning
4. Fuel Consumption Factor set equal to (1+FMS PERF FACTOR(%)/100)
5. Thrust factor set equal to 1.0
6. Atmospheric conditions as close as possible to the ones used by the FMS
7. Cost Index as applicable

4.2.2.2. Flight planning at given speed (CAS/Mach)

The Standard Flight Planning with FMS speeds should be used with the following assumptions:

1. Use Selected mode with FMS regulations
2. FLHV set equal to 18400. BTU/LB (as in the on-board FMS)
3. LO/ECON air conditioning
4. Fuel Consumption Factor set equal to (1+FMS PERF FACTOR(%)/100)
5. Thrust factor set equal to 1.0
6. Atmospheric conditions as close as possible to the ones used by the FMS
7. Speeds as applicable

4.2.3. Determination of the actual aircraft performance

The intent of this paragraph is to explain how to use the FLIP program to calculate the actual aircraft performance.

4.2.3.1. Flight at given Cost Index

Airbus recommendation is to use the Standard Flight Planning with FMS speeds.

The Standard Flight Planning with FMS speeds will perform the ECON speeds and fuel flow calculations. The fuel factor(s) have an influence on these two items. The point is that two different fuel factor(s) must be used:

- FMS PERF FACTOR to obtain ECON speeds
- Monitored fuel factor to obtain fuel flows

In the FLIP, only one consumption factor can be entered. The following gives Airbus recommendations to bypass this constraint.

The FLHV is used during the calculation of fuel flows. Basically speaking the higher the FLHV, the lower the fuel flow. The point is to modify the FLHV by a certain amount in order to compensate for the difference between the FMS PERF FACTOR and the monitored fuel factor, that is to say, to compensate the Basic FMS PERF FACTOR.

As a general assumption, one percent FLHV deviation results in one percent deviation in fuel flow. Then,

$$\frac{FLHV_{CORR} - FLHV_{ACTUAL}}{FLHV_{ACTUAL}} = \Delta FMS\_PERF\_FACTOR(\%)$$

where $FLHV_{ACTUAL}$ is the actual FLHV
$FLHV_{CORR}$ is the corrected FLHV
ΔFMS_PERF_FACTOR(%) is the basic FMS PERF FACTOR in percent

Then,

$$FLHV_{CORR} = \Delta FMS\_PERF\_FACTOR(\%) \times FLHV_{ACTUAL} + FLHV_{ACTUAL}$$

The Standard Flight Planning with FMS speeds mission should be used with the following assumptions:

1. Use ECON speeds (managed mode)
2. Corrected FLHV (see above)
3. air conditioning/anti ice as appropriate
4. Fuel Consumption Factor set equal to (1+FMS PERF FACTOR(%)/100)
5. Thrust factor set equal to 1.0
6. Atmospheric conditions as close as possible to the actual ones
7. Cost Index as applicable

4.2.3.2. Flight at given speed (CAS/Mach)

The Standard Flight Planning mission should be used with the following assumptions:

1. FLHV as appropriate
2. Air Conditioning/Anti Ice as appropriate
3. Fuel Consumption Factor set equal to monitored fuel factor
4. Drag factor set equal to 1.0
5. Atmospheric conditions as close as possible to the actual ones
6. Speeds as applicable

G. POLICY FOR UPDATING THE FUEL FACTOR

1. INTRODUCTION

When implementing routine aircraft performance monitoring one of the tasks is to define some indicators and trigger conditions that may help deciding WHEN to actually change the aircraft fuel factors. The intent of this paragraph is to give Airbus recommendations to the operators updating of the Flight Planning fuel factor and the FMS PERF FACTOR. It is the operator's responsibility to implement this update procedure within its company fuel policy.

The previous paragraphs made an exhaustive review of the different ways to put these indicators into place: monitored fuel factor, monitored delta specific range… This chapter focuses on the main items that must be taken into account and illustrates this with examples coming from the field.

The following is based on Airbus experience as well as on feedback obtained from some operators.

2. STARTING OPERATIONS WITH A NEW AIRCRAFT

At delivery of a new aircraft, no data is available for this tail number to determine the required fuel factors to adjust the computerized flight planning or the FMS predictions. At delivery, it is common practice to perform a flight taking some sample points to establish fuel factors.

With these few points, an FMS PERF FACTOR and a flight planning fuel factor are determined in accordance with chapter *F-Using the monitored fuel factor*. The FMS and flight planning system are adjusted with these factors.

Later on, fuel factors are adjusted for each individual aircraft by means of aircraft performance monitoring. At the very beginning of the operation, an additional cross check may be performed with another method to assess the quality of the aircraft performance monitoring method.

3. A PERF FACTOR FOR EACH AIRCRAFT?

For the sake of simplification, it may be tempting to try and determine fuel factors, applicable to all tail numbers. Indeed, doing so will avoid multiple calculations for a specific aircraft and would allow to use the same flight planning basic information for the whole fleet.
Yet, this will certainly penalize most of the fleet. Indeed, the different tails of an airline are not delivered at the same date. The different aircraft may be allocated on different routes, accumulating different cycles and flight hours. The maintenance done on the aircraft may also result in different consequences for cruise performance analysis (engine change on a specific aircraft will definitively change the monitored fuel factor for the concerned aircraft). To sum up, each individual aircraft has its own history.

Airlines usually tailor the performance factor to each individual aircraft. Refining the cruise performance analysis at the tail number level allows to adjust the book level to the actual aircraft performance of each tail number. Thus, for a given tail number, the computerized flight planning, the FMS predictions and any route study will be customized to each individual aircraft.

It is worth mentioning that the other advantage of routine performance monitoring is that analysis result may evidence unusual conditions by comparing each tail number to the rest of the fleet. Thus, this procedure may also contain trigger conditions for warning the airline maintenance department, in order to keep the aircraft as good as possible.

4. CHANGING THE FUEL FACTOR

4.1. Introduction

Changing the fuel factors is defined in each airline fuel policy. It may vary a lot depending on the airline structure and means available for flight planning and flight operations. The following will show some examples, which cannot be put into place "as is" but should anyway be adapted to each individual airline's needs.

Basically, the fuel factor(s) has(ve) to be updated following noticeable modification of the fuel consumption. Specific attention is required after major maintenance actions (engine change for instance). Such a modification is of course determined based on the aircraft performance history. The point is to identify what lies behind "noticeable modification". This definition is the airline's responsibility.

Indeed, some airlines change the fuel factor as soon as an evolution is detected/monitored, while some others use various smoothing techniques. The difference between the two is of course the margin for conservatism.

Whatever the airline policy, some techniques are usually used to monitor the trend of the fuel factor evolution versus time.

4.2. Some precautions

The following illustrates the way to change the fuel factors throughout aircraft life. The result of cruise performance analysis gives the fuel factor as a function of time. Figure G1 shows an example of monitored fuel factor versus time.

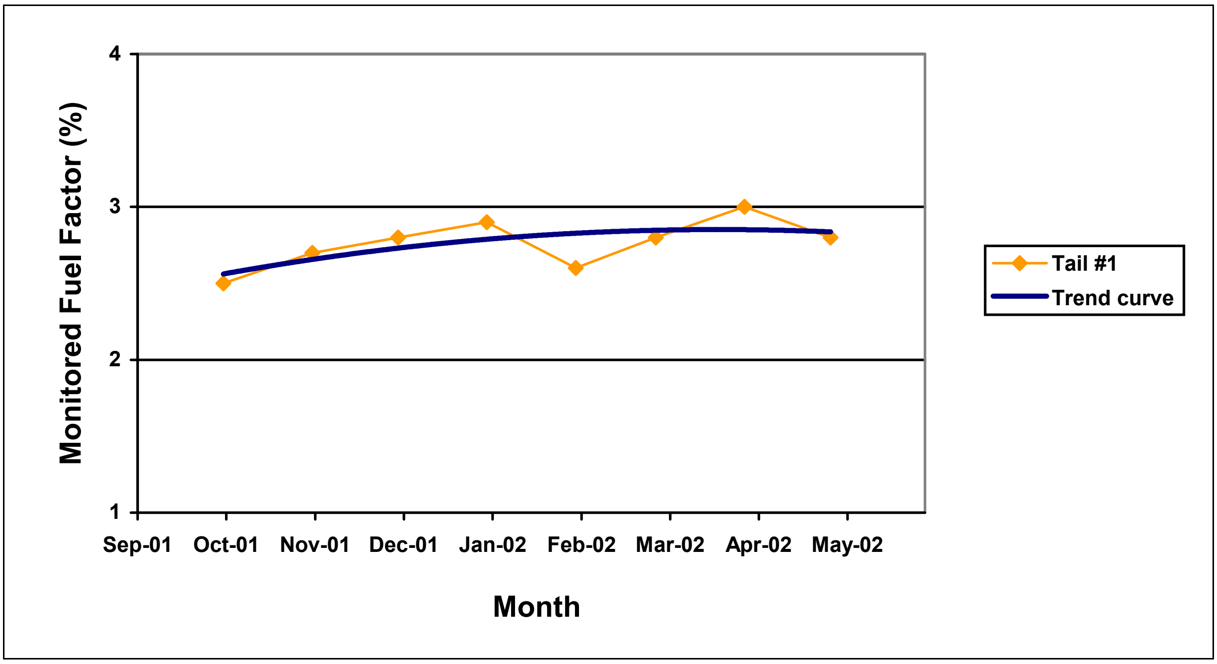


Figure G1 - Example of Monitored Fuel Factor degradation with time

4.2.1. Monitored fuel factor trend line

The monitored fuel factor is established with a certain accuracy level as already explained at the beginning of this brochure. The determination method is a statistical one. For each month, the monitored fuel factor displays a certain scatter. This induces that the trend of the fuel factor is not purely monotonous. The monitored fuel factor can decrease from one month to another, while common sense may make one wonder how aircraft performance can increase with time.

This state of affairs imposes to be careful when changing the fuel factor. Indeed, changing it based on the monitored fuel factor over the preceding month will make the fuel factor go up and down by a few decimals. Some techniques are possible to get around these ups and downs. Some examples are given in paragraphs follows.

4.2.2. Update frequency

Figure G1 shows something interesting about the evolution of the measured fuel factor. Indeed, over 6 months, the monitored fuel factor went up by 0.5%.

As of a consequence, checking the evolution of the monitored fuel factor is useless when it is performed too often. Most of the airlines check fuel factors once a month, which ensures noticeable and acceptable variations.

This rule applies for fuel factors determination. Aircraft performance monitoring with the APM program may also be used to monitor the aircraft and engine condition. In that case, the frequency must be adapted in order not to smooth the variations of the different and to hide some indicators.

4.2.3. Two examples of trigger condition for updating the fuel factors

The two examples explained below illustrate the way the decision to change the fuel factor is made in two different airlines. This procedure depends on the amount of conservatism the airline is ready to add to fuel fact determination of the fuel factor.

Indeed, changing fuel factors too early will increase predicted aircraft fuel consumption on computerized flight planning, leading to possibly carry more fuel than required. Airbus has not yet performed any check concerning the possible impact and is ready to discuss this item with any airline interested in the subject. Yet, the uncertainty on the monitored fuel factor is such that this does not affect the operations in a large extent.

4.2.3.1. Example 1: Step Fuel Factors

The principle of this method is to retain approximate values for monitored fuel factors. The fuel factor is changed when a difference of more than a given percentage is noticed between the new figure and the last one retained. In other words, this technique allows a certain margin or error in the determination of the fuel factor.

Figure G2 on next page shows the actual monitored fuel factor as measured each month, and the associated retained monitored fuel factor.

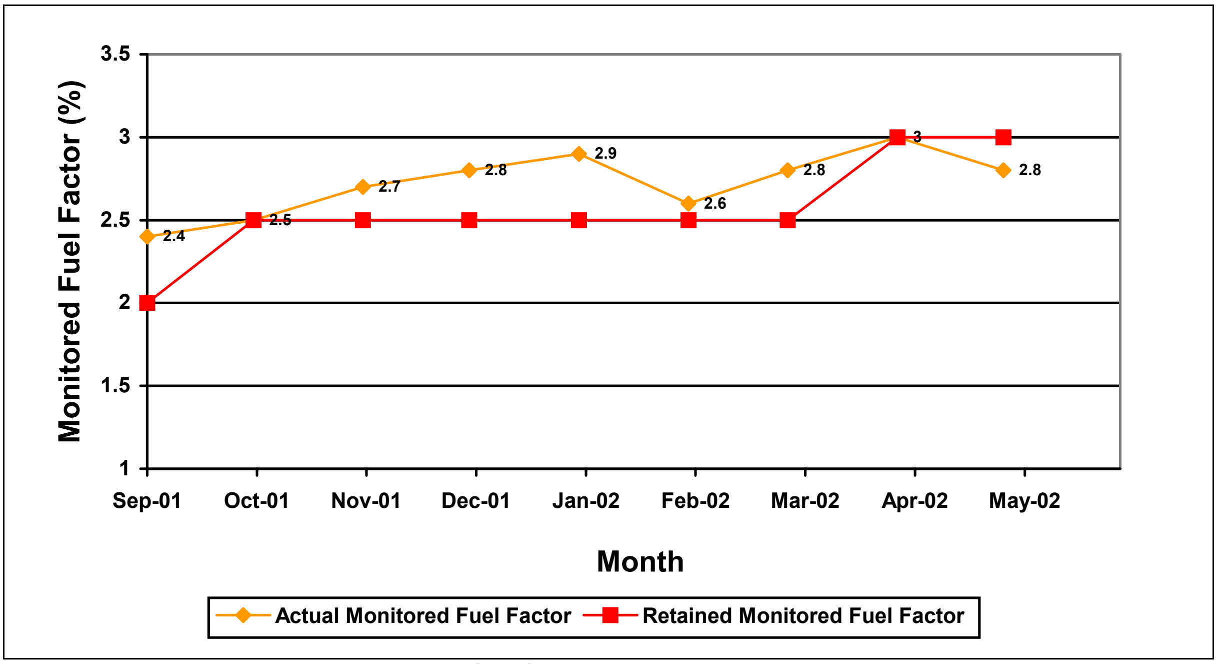


Figure G2 - Step Fuel Factor method

This example assumes a minimum delta of 0.5% is the condition for the update of the fuel factor.

In October 2001, the monitored fuel factor was set to 2.5 %. All the fuel factors (FMS PERF FACTOR, Flight Planning fuel factor…) were updated taking into account this new value.

In the following months, until March 2002, the monitored fuel factor was being evaluated monthly to be compared to the previous one retained (2.5%). None of the monitored fuel factors got above 2.5% + 0.5% = 3.0%, so no update was performed. In April 2002, the monitored fuel factor got equal to 3.0%. The retained fuel factor became 3.0% instead of 2.5%, because the margin was exceeded.
In May 2002, the monitored fuel factor got below 3.0% again. No change is made to avoid ups and downs (which cannot be avoided around the step values).

Definitely the advantage of this method is that it is a simple technique, easily controllable. The only point is to define the margin. In common practice, the determination of the fuel factor is scattered and biased. One should ensure the retained margin does not bias the fuel factor too much.

Using this technique, one could also imagine to retain a more conservative fuel factor envelope (i.e. changing the fuel factor as soon as a monitored factor goes above the retained one). In figure G2, we would set the retained fuel factor to 3.0% starting as from October 2001.

4.2.3.2. Example 2: Smoothed Fuel Factors

The principle of this method is to get rid of the monitored fuel factor variations by smoothing the curve to get a purely monotonous curve.
No more margin is then required. This smoothing technique allows to increase the accuracy of the fuel factor to the decimal. A margin can still be implemented but it can be reduced compared to the previous method.

Generally, this technique is more sophisticated and gives a more accurate trend line.

Figure G3 shows the evolution of the actual monitored fuel factor and the retained one over time. The actual monitored fuel factors were averaged over the last three months, which gives quite acceptable results and trends.

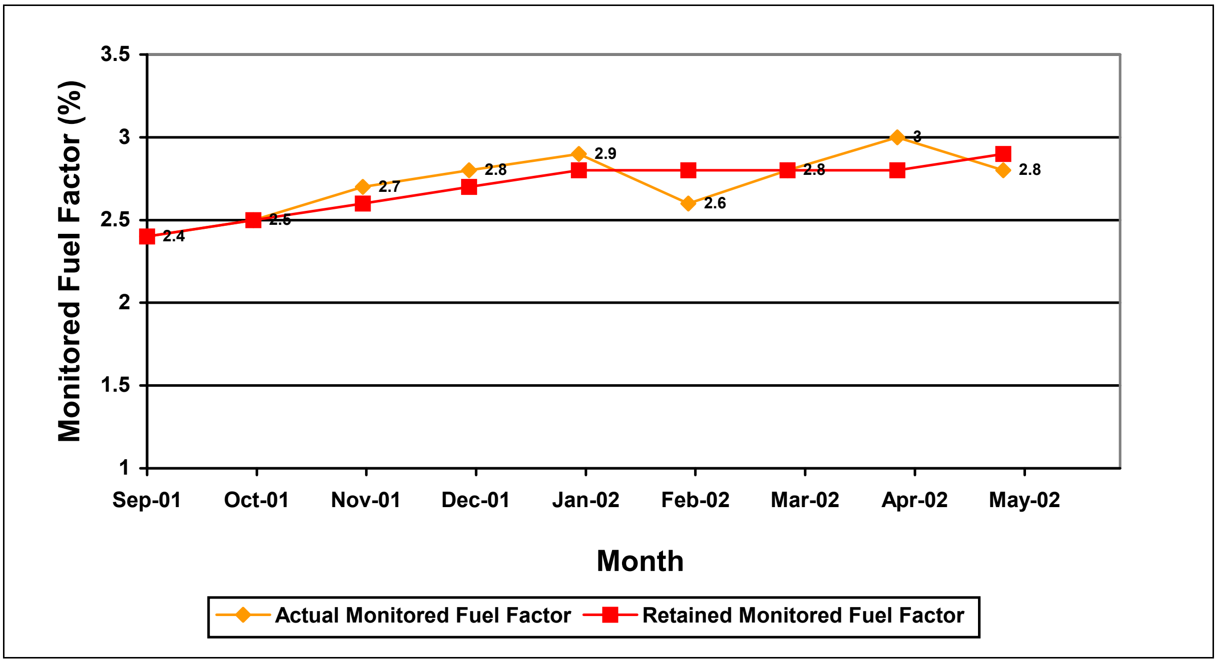


Figure G3 - Smoothed Fuel Factor method

In September 2001, the first available monitored fuel factor is retained.
In October 2001, the monitored fuel factor is 2.5%. Averaging this factor with the September one gives 2.45%, which is rounded up to 2.5%. The retained fuel factor is 2.5%.
In November, the average is performed over the past three months. 2.4% in September, 2.5 in October, and 2.7% in November. The retain fuel factor is the average of the three, 2.6%.
In December, the average of the actual fuel factors over October, November and December results in a 2.7% fuel factor being retained.

Using this technique is a little bit more sophisticated than the previous. The advantage of the method is that it minimizes possible errors and allows to really stick to the fuel factor trend line.

Of course, this smoothing technique is a quite simple (but efficient) one, and one could imagine developing a specific smoothing technique based on polynoms or the like. Airbus is prepared to share its view with any airline interested, and for the sake of airline operations improvement.

5. WHO CHANGES THE FUEL FACTOR(S)?

The intent of this paragraph is to give the Airbus view on who must be informed of a change of fuel factor on one hand, and who should have the authority to do so. It does not impose any way of working neither aim to substitute to any airline practice.

Airline Flight Operations staff members should define the different fuel factor(s) based on an aircraft performance monitoring method. For routine aircraft performance monitoring, the Specific Range method and the use of the APM program will facilitate recurrent analysis.

Note: The AMM does not provide any procedure to change this factor.

Airline Flight Operations will trigger a change in fuel factor(s) and provide the relevant figures to supervisory management and to operational teams:

- in charge of the flight planning system update (Flight Planning Office)
- in charge of updating of the FMS PERF FACTOR on board the aircraft (Maintenance, Avionics…)

LEFT INTENTIONALLY BLANK

H. APPENDICES

This chapter gathers additional material dealing with aircraft performance monitoring.

1. APPENDIX 1 : HIGH SPEED PERFORMANCE SOFTWARE

1.1. P.E.P for Windows

1.1.1. What is P.E.P. ?

The PEP for Windows working environment aims at providing the necessary tools to handle the performance aspects of flight preparation, but also to monitor aircraft performance after flight. It is dedicated to airlines' Flight operations and design offices. Based on the Microsoft Windows © operating system, the PEP for Windows is a stand-alone application, which offers access to all the Airbus aircraft performance computation programs in a user friendly and customizable environment. In addition to an easy-to-use setup tool, useful tools like the "Airport Manager", the "Batch manager" and the "On-line Help" have been implemented

1.1.1.1. Objectives

In order to better understand the main objectives of the PEP for Windows working environment we first need to recall that the previous working environment was based on the DOS operating system. Each performance calculation program had been developed separately from the others.
This is why the main objectives of this working environment are :

- To provide a working environment using the Microsoft Windows © operating system for all Airbus performance computation programs.
- To harmonize layout and behavior of all program interfaces.
- To improve user-friendliness of these user interfaces.
- To develop and introduce new tools in order to ease the handling and management of data.
- To improve access to Performance Programs documentation by the user thanks to an On-line Help.

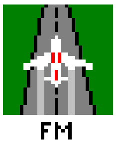
Some of these objectives have been achieved through one of the PEP version 1 (16-bit for transition) and others through the PEP version 2 (32-bit).

1.1.1.2. Scope

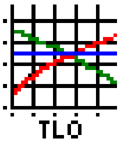
The PEP for Windows working environment is applicable to all Airbus Performance Calculations.
Calculation programs plugged into the PEP for Windows structure provide "low speed" and "high speed" performance for all A320 FAMILY, A300, A310, A330 and A340 Airbus aircraft types.

1.1.2. Performance Computation Programs

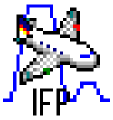
The PEP for Windows platform provides access to the following Airbus Aircraft Performance Programs :



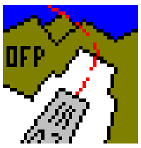
FM program: It is the computerized Flight Manual and it covers the TAB program for A300-600, A310 and A320 (certified for A320 only) and the certified part of the OCTOPUS program for A319, A321, A330 and A340.



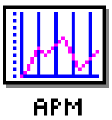
TLO program: It allows takeoff and landing optimization including "Takeoff Charts" and it consists of TLC (or TCP program for A300), for A310 and A320 and the former optimization part of the OCTOPUS program for A319, A321, A330 and A340.



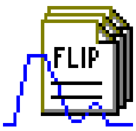
IFP program: It provides aircraft performance for "High Speed" flight phases such as climb, cruise, descent, … and also includes a consultation tool of aerodynamic and engine data. It is applicable to all Airbus aircraft types.



OFP program: It is devoted to determining the aircraft trajectory (all engine operating) and various configuration parameters for a user defined flight path at takeoff or in approach (i.e. Low Speed phases). It also computes trajectories (with cutbacks for example) for noise level determination, which then becomes an input for the NLC program. It is applicable for all Airbus aircraft types (but with possible production delays for some of them).



APM program: It allows the user to compare and monitor the actual aircraft In-flight performance level versus the theoretical baseline all along the aircraft life for all Airbus aircraft types.



FLIP program: It is a Flight planning software, which can compute a complete mission (standard, reclearance or ETOPS) for a given ground distance and an average wind, including taxi, diversion to alternate, route reserves, … , for all Airbus aircraft types.

NLC program: It has replaced the Noise Definition Manual (NDM) for some aircraft types and can compute on ground and in flight noise level for all Airbus aircraft types. The In-flight part of NLC uses flight paths calculated with the OFP program at takeoff or in approach.

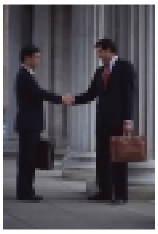
1.1.3. The IFP program

The In Flight Performance program is the first program for high speed performance calculation within the PEP package.
This tool is an engineering oriented tool and as such it is to be used within the frame of specific studies and various calculations required by the day-to-day work of an operation engineer.

The main tasks in which the IFP program can assist the engineer are:

- Computation of instantaneous or integrated performance data for a flight phase
- Simulation of FMS computation
- Extraction of aerodynamic characteristics and engine performance data for an aircraft model

1.1.4. The APM program



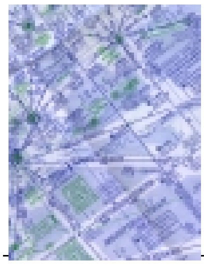
For years, the business environment has been becoming more and more challenging. Yields are dropping while competition is increasing. Business traffic is volatile, aircraft operations are becoming more and more expensive and the price of spare parts are escalating faster and faster. Airlines have to face with new objectives to adapt to this environment.

Fuel burn makes up for ten percent of the direct operating costs. Engine maintenance makes up for another quarter. The operator's main concern is therefore to have high quality information about the condition and the performance of the aircraft whenever needed.

That's why Airbus feels deeply involved in aircraft performance monitoring and as a consequence has been proposing for years some tools for aircraft performance monitoring as well as some guidelines for performing aircraft performance audits.

Airbus has developed one tool within its aircraft performance software devoted to cruise performance analysis: the Airbus *Aircraft Performance Monitoring* program (APM).

1.1.5. The FLIP program

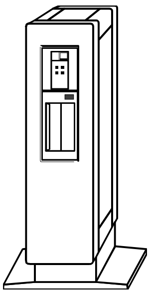


Flight Planning is one of the major tasks of a dispatcher. Two essential aspects have to be examined when a new route is to be opened: Feasibility and economics. Both involve an accurate and representative estimation of the fuel burn that has to be expected on the given route.

Commercial flight planning providers like Jeppesen, SITA or Air Data provide accurate routing information taking into account actual weather conditions, but these systems work with pre-calculated aircraft performance data.

For some critical routes, this level of precision may not be high enough to allow for a financially sound operation. This is why Airbus provides the ability for the operator to validate the fuel burn predicted by such commercial flight plans with its own software, the FLIP.

1.2. SCAP Programs and Unix Versions



Airbus Flight Operations Support & Line Assistance Department regularly participates to the IATA SCAP (Standard Computerized Aircraft Performance) meetings with other manufacturers and airlines representative.

In accordance with the “Standard definition” agreed by all participants to these meetings, Airbus provides Airlines Flight Operations with “SCAP compliant” computation programs written in FORTRAN 77.

These calculation programs are called “SCAP programs”. Subsequently, each operator, has to write its own calling program, which defines each input parameter, calls the calculation sub-routine and recovers the output parameters.

The available “SCAP Programs” are:
- SCAP TAKEOFF (OCTOPUS-SCAP-TAKEOFF or ATAM for takeoff performance optimization),
- SCAP LANDING (OCTOPUS-SCAP-LANDING or ALAM for landing performance optimization),
- SCAP CLIMB-OUT (for takeoff or approach trajectories computation),
- SCAP IFP (for in-flight performance computation),
- SCAP APM (for aircraft performance monitoring).

The SCAP programs are not embodied in the PEP for Windows environment, but are available upon request from operators receiving the PEP for Windows product.

2. APPENDIX 2 - FUEL-USED METHOD

2.1. General Principle

The basis of the Fuel Used method is to measure the fuel burnt by the aircraft in level flight and to compare it to the fuel burn prediction of the IFP for the given flight conditions and time span.

The Fuel Used (FU) analysis is conducted under normal flying conditions and does not require stabilized conditions. It is less restrictive then the Specific Range (SR) analysis in terms of stability and data acquisition requirements, the autothrottle being allowed to remain selected.

As an alternative method, it is sufficient to check or prove the accuracy or confidence level of the applied flight planning method since it accounts for all operational factors such a ATS on, CG movements, aircraft maneuvering, flight path and vertical accelerations, weather influences, etc. The FU method is used as a complement so as to account for changing external or flight conditions. It is also used whenever the stabilization criteria required for the SR method cannot be met (e.g. short legs, turbulence areas…).

Indeed, the SR method is based on a short time span measurement that needs to satisfy stringent criteria, the FU method relies an a long time span measurement (not shorter than 30 minutes) that is very flexible in terms of data acquisition requirements. Although it is more easily integrated into daily cockpit recording, the efficiency of this method is not very high. Due to the relatively long time intervals (around 40 minutes) the relevant parameters change significantly and require careful integration (averaging) time to avoid misleading conclusions. Conclusions of the FU method are only suited to operationally oriented departments as technical engineering departments. Do not attempt to obtain the diagnostic information potentially available from the SR method trends.

Fuel consumption is determined by subtracting fuel used indications at time over station (from switchover on FMS and RMI bearings). Time between stations ΔT is determined from a personal stopwatch chronometer.

At high drift angles (> 5 degrees) the wind triangle equations must be taken into account to correctly calculate TAS, GS and longitudinal wind component.

The FU method is operationally attractive but can only be accomplished if conditions and procedures specified above are strictly and precisely adhered to. This makes this improved version of the FU method cumbersome to apply, although it is easy to integrate into normal aircraft operating procedures.

2.2. Measurement procedures and precautions

The next page figure shows a sample recording form for handwritten observations.

2.2.1. Prior to take-off

- Calculate fuel on board at MES by taking remaining fuel + truck uplift (measured at truck) accounting for actual fuel density.
- Determine ZFW and take-off CG
- Note APU running time since MES
- Compute APU fuel consumption to amend FU

AMP WT AT MES :
APU RUNNING TIME AFTER MES :
AIR CONDITIONING:BLEEDS : E or N

TCC : ON
OFF

ATS : ON
OFF
AUTOPILOT :
C.G. (EST) :

DRIFT :

RUDDER : NR/NL
HOR. STAB :
ZCW or WLV ϕ

DATE :
FLIGHT :
SECTOR :
AIRCRAFT :

UTC	ΣFQI FU1/FU2	HDG W/V TRACK/COURSE	ALT	V_C/M	$SAT_{(TAT)}$	TAS/V_G/kt	N_{11} /N_{12}	FF_1 / FF_2
			ADC1 and/or ADC2	ADC1 and/or ADC2	ADC1 and/or ADC2	ADC1 and/or ADC2		

Figure 6

2.2.2. In flight

- Verify aircraft to be flying level in cruise for at least 40 minutes
- Perform fuel balancing if tank balance exists
- Establish nominal aircraft configuration for the cruise segment where measurements will be taken, i.e. :

- **Autothrottle:**	ON
- **Autopilot:**	As required e.g. ALT HLD / HDG / NAV
	or ALT HLD / NAV
	or PROF / NAV
- Air conditioning:	NORM
- Anti-icing:	OFF
- **Trimming:**	ZCW on A310 / A300-600

- Whenever possible, the analysis will be conducted on selected data frames, meeting the following stability criteria:
  - ΔZp < 50 feet/ 30 minutes
  - ΔSAT < 5°C / 30 minutes
  - ΔGS < 10 kts / 30 minutes
  - ΔTAS < 10 kts / 30 minutes

- Note the accurate values of fuel used engine 1 & 2 (FU1 & FU2) at initial time
- Record data for at least 30 minutes, if conditions permit, from start of period every 5 minutes until the end, using adjacent fuel-used recording form:

- UTC, latitude or station	- Track / course
- CG,	- Wind speed / direction
- FU_1 / FU_2	- Heading and drift
- Total fuel on board (FQI)	- TAS / Ground Speed
- altitude (Zp) – (channel 1 and 2)	- N_{11} / N_{12} (EPR_1 / EPR_2) (engine 1 & 2)
- Mach – (channel 1 and 2)	- FF_1 / FF_2 (engine 1 & 2)
- SAT / TAT	

- Note the accurate values of fuel used engine 1 & 2 (FU1 & FU2) at initial time
- Note also latitude or station approaching, drift, heading, wind velocity / direction, track / course for calculation of effects mentioned in section 3.
- Do not forget to consult weather charts (forecasts and actual) to confirm pressure patterns
- On A310/A300-600, do not omit to mention TCCS / ARCCS on or off
- Do not omit to note tail number, date flight sector for referencing

2.3. Data analysis procedure

Based on the flight data over the recorded time span, the following parameters will be calculated:

– Time span (ΔT) = UTC_{Stop} – UTC_{Start}
– Gross weight at start
– Average altitude (Zp)
– Average Mach number (M)

- Average TAT/SAT
- Fuel used = (fuel used at end – fuel used at start) or (FQI start – FQI end)
- Aircraft CG (based on takeoff CG and fuel burn schedule (if not mentioned).

The IFP is then used to compute the predicted fuel used for the aircraft flying at the average recorded flight conditions, over a time span equal to Δt and starting at a weight equal to GW start. The ratio of measured and predicted fuel used will provide the level of performance relative to the published model. The following schematic shows the procedure flow:

2.3.1. Notes

1) Selection of several 40-minutes samples from the recorded data allows a mean value to be obtained and measurement scatter to be evaluated, which is indicative of flight stability and smoothness.

2) The improved FU method (whose principle is explained in paragraph 2.2.1) gives refined results and allows very precise measurements.

LEFT INTENTIONALLY BLANK

LEFT INTENTIONALLY BLANK

3. APPENDIX 3 - TRIP FUEL BURN-OFF METHOD

This method compounds genuine performance (engine/airframe, instrument accuracy) with apparent performance deviations caused by differences between the actual flight profile (and conditions) and the IFP – predicted flight profile (and conditions) such as:

- Wind and SAT profile predictions,
- Flight profile (Climb profile, Top of Climb, Cruise Mach, Step Climbs, Top of Descent, Descent profile, Holding) predictions.
- Fuel burn-off predictions (model, performance factor, LHV)
- Operational factors (e.g. center of gravity position, air conditioning mode, aircraft weight, aircraft trimming).
- Environmental factors (e.g. coriolis-Effect, local gravity, centrifugal effect, isobaric slopes caused by pressure and temperature gradients).

As in the FU-method all flight parameters are averaged over time segments to allow a numeric approximation per flight phase prior to input into the flight plan recalculation.

AIRBUS IFP-V0ZA P   JUNE 1989
A310-304-01   CF6-80C2A2

CLEAN CONFIGURATION

C G POSITION : 36.9 %

AVERAGE ENGINE - FLHV : 18570.BTU/LB

WITHOUT ANTI-ICING ECONOMIC AIR CONDITIONNING

ALTITUDE : 35018.FT   ISA + 12.3 DG.C   WIND : 4.3 KT

CONSUMPTION: — for [illegible]

CRUISE AT .802 MACH NUMBER

OPTIMAL WEIGHT FOR FLIGHT LEVEL IS 129665. KG
THRUST LIMITED WEIGHT   EXCEEDS STRUCTURAL LIMIT
BUFFET LIMITED WEIGHT   EXCEEDS STRUCTURAL LIMIT

WGHT (KG)	MACH ( )	CAS (KT)	TAS (KT)	TIME (MN)	FUEL (KG)	DIST (NM)	SR (NMKG)	WFE (KG/H)	N1 (%)	EGT (DG.C)	CL ( )	CD ( )	ALPH (DEG.)	FN (DAN)	PCFN (%)
	.802	272.6	475.1 *	.00	0.	.0	.09732	4926.	94.840	687.	.57290	.03338	2.24	7869.	80.8
137000.	.802	272.6	475.1	16.37	1336.	130.8	.09846	4869.	94.547	684.	.56742	.03296	2.20	7769.	79.0
136000.	.802	272.6	475.1	28.75	2336.	229.7	.09932	4826.	94.331	681.	.56331	.03265	2.17	7695.	79.0
135000.	.802	272.6	475.1	41.23	3336.	329.4	.10019	4785.	94.116	679.	.55921	.03234	2.14	7621.	78.2
134226.	.802	272.6	475.1	50.97	4110.	407.2	.10081	4755.	93.965	678.	.55603	.03212	2.12	7569.	77.7

AIRBUS IFP-V0ZA P   JUNE 1989
A310-304-01   CF6-80C2A2

CLEAN CONFIGURATION

C G POSITION : 36.9 %

AVERAGE ENGINE - FLHV : 18570.BTU/LB

WITHOUT ANTI-ICING ECONOMIC AIR CONDITIONNING

ALTITUDE : 35018.FT   ISA + 12.3 DG.C   WIND : 4.3 KT

CRUISE AT .805 MACH NUMBER

OPTIMAL WEIGHT FOR FLIGHT LEVEL IS 130659. KG
THRUST LIMITED WEIGHT   EXCEEDS STRUCTURAL LIMIT
BUFFET LIMITED WEIGHT   EXCEEDS STRUCTURAL LIMIT

WGHT (KG)	MACH ( )	CAS (KT)	TAS (KT)	TIME (MN)	FUEL (KG)	DIST (NM)	SR (NMKG)	WFE (KG/H)	N1 (%)	EGT (DG.C)	CL ( )	CD ( )	ALPH (DEG.)	FN (DAN)	PCFN (%)
138336.	.805	273.7	476.8	.00	0.	.0	.09684	4968.	95.016	689.	.56869	.03339	2.19	7927.	81.5
137000.	.805	273.7	476.8	16.23	1336.	130.2	.09805	4907.	94.703	686.	.56325	.03293	2.15	7820.	80.3
136000.	.805	273.7	476.8	28.52	2336.	228.7	.09897	4861.	94.469	683.	.55918	.03260	2.12	7740.	79.5
135000.	.805	273.7	476.8	40.91	3336.	328.1	.09978	4822.	94.267	681.	.55511	.03231	2.09	7670.	78.8
134226.	.805	273.7	476.8	50.57	4110.	405.5	.10037	4794.	94.122	679.	.55195	.03210	2.07	7621.	78.3

4. APPENDIX 4 - AIRBUS SERVICE INFORMATION LETTER 21-091

CUSTOMER SERVICES DIRECTORATE
1 ROND POINT MAURICE BELLONTE
31707 BLAGNAC CEDEX FRANCE
TELEPHONE + 33 (5) 61 93 33 33
TELEX AIRBU 530526F

AIRBUS INDUSTRIE

SERVICE INFORMATION LETTER

SUBJECT: **PACK FLOW INDICATION – TROUBLE SHOOTING GUIDELINES**

ATA CHAPTER: 21-50

AIRCRAFT TYPE: ALL A319/A320/A321

APPLICABILITY: A319/A320/A321

REFERENCES:

1. **PURPOSE:**

The purpose of this S.I.L. is to provide information regarding pack flow indication and to assist trouble shooting when an abnormal flow indication is reported.

SIL NUMBER:	21-091
PAGE:	1 of 6
DATE:	May 13/97
REVISION:	01, Jan 20/99

AIRBUS INDUSTRIE

SERVICE INFORMATION LETTER

2. BACKGROUND:

2.1. Flow indication background

In the past reports were received from a number of operators regarding pack flow indication discrepancies. This led to the definition of a more accurate pressure sensor PN 9104A0003-01 and of a new pack controller (PC) standard –A09.

Following the introduction of the improved sensor and pack controller –A09, further flow discrepancies were seen on ground and in flight. On ground the error of the flow indication was in the range of plus or minus 10 percent whereas in flight it could reach 30 percent below actual flow rate (at 39000 FT).

The computation of the output signal of the pressure sensor by the pack controller, as well as discrepancies in the dimensions of the clapper of the flow amplifier, were found to be the source of the remaining inaccuracies.

The following modifications were defined in order to further improve the indication loop accuracy :

- Changes to the pack controller software such that the demand flow (the tolerance band corresponding to the maximum error of the measurement system which is plus or minus 15 percent). The actual measured flow will however be displayed if it is determined to be outside the tolerance band. This improvement is available within PC –A10 standard (SB A320-21-1092), PC –C02 standard (post-mod 23987) for and PC –D01 standard (post-mod 26792). It should be noted that under APU bleed this logic is inhibited and only the actual measured flow is displayed.

- New design of the flow control valve (FCV) flow amplifier, this being available within the FCV PN 751A0000-07 for A319/A320 and the FCV PN 751B0000-02 for the A321.

- Introduction of a new flow package. The new standard of FCV PN 1303A0000-01 has electro-pneumatic flow control in place of pneumatic flow regulation in order to increase resistivity to contamination. This FCV PN 1303A0000-01 may only be used on conjunction with PC 759D0000 – 01, Pack Inlet Pressure Sensor (PIPS) 9104A0006-01 and Differential Pressure Sensor (DPS) 9106A0005.

See figure 1 for modification effectivity.

2.2 Flow indication display

The pack flow indication is displayed on the ECAM BLEED page.

This page is automatically displayed when a failure is present within the pneumatic system or within the air conditioning pack system.

The flow indication is displayed green and varies from LO to HI. It becomes amber if the pack flow control valve is closed.

SIL NUMBER:	21-091
PAGE:	2 of 6
DATE:	May 13/97
REVISION:	01, Jan 20/99

AIRBUS INDUSTRIE

SERVICE INFORMATION LETTER

For aircraft equipped with the Aircraft Integrated Data System (AIDS) option, flow indication is also available through the AIDS parameters on the MCDU :

- AIDS/ALPHA CALL-UP : programmation of pack flow (PF) for real time reading
- AIDS/PROGRAMMABLE REPORT 16/CODE BLEED STATUS
- AIDS/ECS REPORT 19 : PF (pack flow)

2.3 Flow indication on ground under APU bleed

Under APU bleed the actual measured flow is displayed (regardless of pack controller standard).

The flow control valves are automatically controlled to regulate to the HI flow level (120 %). When the ECS demand to the APU is 100 % , depending on the APU type and the electronic control box (ECB) which is installed, the flow delivered by the APU will vary from about 0.97 kg/s to 1.05 kg/s at the design point (38°C/45 % rel. humidity) assuming that the APU performance capabilities are not degraded.

For the A319/A320 aircraft, when the FCV is controlled to regulate to the HI flow level on ground, a maximum flow of 1.32 kg/s (0.66 kg/s per FCV) into the cabin is possible. For the A321 aircraft the maximum possible flow is approximately 1.5 kg/s (0.75 kg/s per FCV).

Under normal conditions however the APU is limited to a lower threshold than these maximum values. Consequently, on ground, under APU bleed, the flow control valves will be fully open with a LO flow indication displayed on ECAM (measured flow being lower than the calculated flow).

In this case the flow indication under APU bleed on ground should be disregarded and should not lead to a technical entry or the conclusion that flow control valve regulation or indication is faulty.

However, with only one pack operation, good flow accuracies may be obtained from the APU bleed supply. This configuration allows an operational test of the flow control and indicating system to be carried out under APU bleed supply, as per AMM page block 21-51-00-710. This is also reflected in the TSM.

2.4 Flow indication in flight

When pack flow indication is reported abnormal by the pilots in flight it is first recommended to check PC standard, FCV standard and pressure sensor standard (DPS for FCV PN 130340000-01) for compatibility.

In the case the flow is reported HI, whatever is the flow selector position, an abnormally high regulation of the FCV could be suspected. For Amdt. B (A321) and Amdt. C (A319/A320) FCV's, this may indicate a clogged filter.

AIRBUS INDUSTRIE

SERVICE INFORMATION LETTER

Therefore clean or replace the filter, and if the fault persists the FCV.
If it is reported LO it could be due to a drift of the indication or to an abnormally low regulation of the FCV. In any case a NOTE is provided in the FCOM 1.21.10 to advise the pilot that flow indication is not accurate.

2.5 Trouble shooting guidelines for incorrect indication

In the case of an entry in the technical log book for abnormal flow, with the FCV 751A, 751B or 1303A installed, the following procedure should be applied on ground to determine whether flow indication misbehaviour is due to the FCV or to the indication loop.

On ground under engine bleed or pre-conditioning through the HP ground connection/PACK 1 and PACK 2 selected on :

- Ensure that bleed pressure on ECAM BLEED page is higher than 24 psig.
- Select PACK FLOW LO : minimum indication should be "LO". Indication should not go above the eleven o'clock position.
- Select PACK FLOW NORM : indication should not go below the eleven o'clock position and above the one o'clock position.
- Select PACK FLOW HI : indication should not go below the one o'clock position

If flow indication is within the above tolerances, no maintenance action is required, i.e. that the origin of the discrepancy is flow indication inaccuracy. If the flow indication is outside the tolerances, it can be considered to be a genuine flow discrepancy and as such the associated FCV should be replaced.

Note : This procedure is also valid for aircraft equipped with previous standards of FCV. This test however may not confirm a genuine flow discrepancy since earlier FCV standards are known to cause flow indication inaccuracy.

If pack flow indication is accessible via the AIDS parameters on the MCDU, select the PACK FLOW to the NORM position (100 %) and, under engine bleed with both packs selected ON, ensure that the flow in kg/s through each pack (Alpha call up PF) is as follows :

A319/A320 : $0.47 < PF < 0.63$

A321 : $0.55 < PF < 0.74$

If pack flow is not within these limits it is recommended to replace the associated flow control valve (FCV).

This procedure has been included in the TSM.

SIL NUMBER:	21-091
PAGE:	4 of 6
DATE:	May 13/97
REVISION:	01, Jan 20/99

2.6 General statement on flow indication

As per the design, the accuracy of the pack flow information on the ECAM BLEED page alone is not sufficient to provide a good indication of pack FCV condition. The ECAM flow indication is not required for the aircraft dispatch and is not required for troubleshooting of the ECS. The indication is in fact only intended to confirm the presence of flow through the FCV, but it is only valid under engine bleed conditions, or one pack operation under APU bleed supply.

The pack flow indication can therefore normally be disregarded. Incorrect operation of the ECS system will be indicated by either an amber indication (high compressor discharge temperature, high pack discharge temperature, FCV closed), an ECAM warning, a local fault warning or a CFDS message.

3. MATERIAL INFORMATION

Not applicable.

4. PROCUREMENT INFORMATION

Not applicable.

3. EFFECTIVITY

See effectivity box.

AIRBUS

COMPONENT	PN	INTRODUCED BY		EMBODIMENT RANK
		MOD	SB	
Flow sensor	9104A003-01	22781	A320-21-1052	320
Pack Controller	759A0000-09	22898	A320-21-1052	320
Pack Controller	759A0000-10	24094	A320-21-1082	482
Pack Controller	759A0000-11	27469	A320-21-1111	N/A
Pack Controller	759A0000-02 (basic on A321 on EIS)	23987	A320-21-1106	628
# Pack Controller	759D0000-01	26792	N/A	869
# Pack Controller	759D0000-02	TBD 28488	TBD VSB 759D-21-01	TBD 1059
Flow Control Valve	751A0000-07	23824	VSB751A-21-05	470
Flow Control Valve	1303A0000-01	26249	N/A	869
Flow Control Valve	1303A0000-02	~~TBD~~ 28302	TBD VSB 1303A-21-01	TBD 1012
# Pack Inlet Pressure Sensor	9104A0006-01	26249	N/A	869
# Differential Pressure Sensor	9104A0005-01	26249	N/A	869

Flow control valve 751A0000-B02 was basic on A321 at entry into service. FCV 1303* must be used in conjunction with items marked #

SIL NUMBER:	21-091
PAGE:	6 of 6
DATE:	May 13/97
REVISION:	01, Jan 20/99

5. APPENDIX 5 - AMM EXTRACTS - CRUISE PERFORMANCE REPORT <02> DESCRIPTION EXAMPLE

The following pages show an example of technical description for the DMU/FDIMU cruise performance report. The following was extracted from a documentation for an A320 aircraft fitted with an IAE engine.

As a reminder, this file may be used as the primary source of information for routine performance monitoring.

Code No.	Item No.	Description of Function Item	Progr. MCDU GSE	Standard Value or Table TXY
AI = Programmable by Airbus Industrie				
C = Programmable by Customer				

L. Cruise Performance Report <02>
(Ref. Fig. 012)
The cruise performance report is a collection of aircraft and engine information averaged over a period of time in which both the engine and the aircraft met the appropriate stability criteria. The cruise performance report is generated when one of the logic conditions 1000 to 5000 (for details see cruise performance report logic) is present.

(1) Cruise Performance Report Data Field Description (Engine Type IAE)

Value	Content Description
TAT/ALT/CAS/ MN/GW/CG	In the report line CE is the averange value for F02 * 20 sec. of System 1 parameters printed. In the report line CN is the averange value for F02 * 20 sec. of System 2 parameters printed.
ESN 999999	Engine Serial Number (000000 to 999999) Eng 1 param. 7C.1.046.01 digit 3, 2, 1 7C.1.047.01 digit 6, 5, 4 Eng 2 param. 7C.2.046.01 digit 3, 2, 1 7C.2.047.01 digit 6, 5, 4
EHRS 99999	Engine Flight Hours (00000 to 99999 hours) DMU Engine 1 and Engine 2
ECYC 99999	Engine Cycle (00000 to 99999)
AP 99	Auto Pilot Status (00 to G8) FMGC 1 and 2 (FGC part) for Auto Pilot AP1 and AP2

```
          111111111122222222223333333333334
 1234567890123456789012345678901234567890
+----------------------------------------+
|            3 Lines                     |
|                                        |
|         free programmable              |
|                                        |
|         per report                     |
|                                        |
|   A3XX CRUISE PERFORMANCE REPORT <02>  |
|                                        |
|   A/C ID DATE  UTC    FROM TO   FLT    |
|CC XXXXXX AAA99 999999 AAAA AAAA 9999   |
|                                        |
|   PH CNT   CODE BLEED STATUS      APU  |
|C1 99 99999 9999 99 1111 1 1111 99 1    |
|                                        |
|   TAT  ALT   CAS MN  GW   CG  DMU/SW   |
|CE X999 X9999 999 999 9999 999 XXXXXX   |
|CN X999 X9999 999 999 9999 999          |
|                                        |
|   ESN    EHRS  ECYC  AP QA QE          |
|EC 999999 99999 99999 99 99 99          |
|EE 999999 99999 99999 99                |
|                                        |
|   EPR  EPRC EGT  N1   N2   FF   P125   |
|N1 9999 9999 X999 9999 9999 9999 99999  |
|N2 9999 9999 X999 9999 9999 9999 99999  |
|                                        |
|   P25   T25  P3   T3   P49   SVA       |
|S1 99999 X999 9999 X999 99999 999       |
|S2 99999 X999 9999 X999 99999 999       |
|                                        |
|   BAF ACC LP GLE PD TN  P2    T2       |
|T1 999 999 01 999 99 X99 99999 X999     |
|T2 999 999 01 999 99 X99 99999 X999     |
|                                        |
|   ECW1  ECW2  EVM   OIP OIT OIQH       |
|V1 XXXXX XXXXX XXXXX 999 X99 X999       |
|V2 XXXXX XXXXX XXXXX 999 X99 X999       |
|                                        |
|   VB1 VB2 PHA                          |
|V3 999 999 999                          |
|V4 999 999 999                          |
|                                        |
|   WFQ   ELEV AOA  SLP  CFPG  CIVV      |
|X1 99999 X999 X999 X999 X9999 X999      |
|X2 99999 X999 X999 X999 X9999 X999      |
|                                        |
|   RUDD RUDT AILL AILR STAB ROLL YAW    |
|X3 X999 X999 X999 X999 X999 X999 X999   |
|                                        |
|   RSP2 RSP3 RSP4 RSP5 FLAP SLAT        |
|X4 X999 X999 X999 X999 X999 X999        |
|X5 X999 X999 X999 X999 X999 X999        |
|                                        |
|   THDG LONP  LATP WS  WD  FT   FD      |
|X6 9999 X9999 X999 999 999 X999 0999    |
|X7 9999 X9999 X999 999 999 X999 0999    |
```

NM6 31 36 00 0 AVNA 01

Cruise Performance Report <02>
(Engine Type IAE)
Figure 012

```
+---------------------------------------------------------------------------+
| Value          |                Content Description                       |
|----------------|----------------------------------------------------------|
|                |   XX Auto Pilot Modes:                                   |
|                |   ||                                                     |
|                |   ||__Lateral Modes: 0 = NO MODE                         |
|                |   |                  1 = HEADING                         |
|                |   |                  2 = TRACK                           |
|                |   |                  3 = NAV                             |
|                |   |                  4 = LOC CAPTURE                     |
|                |   |                  5 = LOC TRACK                       |
|                |   |                  6 = LAND TRACK                      |
|                |   |                  7 = RUNWAY                          |
|                |   |                  8 = ROLL GO AROUND                  |
|                |   |                                                      |
|                |   |__Longitudinal Modes: 0 = NO MODE                     |
|                |                        1 = PITCH G/A                     |
|                |                        2 = PITCH T/O                     |
|                |                        3 = G/S TRACK                     |
|                |                        4 = G/S CAPTURE                   |
|                |                        5 = V/S                           |
|                |                        6 = FPA                           |
|                |                        7 = ALT                           |
|                |                        8 = ALT ACQ                       |
|                |                        9 = OPEN CLB                      |
|                |                        A = OPEN DES                      |
|                |                        B = IM CLB                        |
|                |                        C = IM DES                        |
|                |                        D = CLB                           |
|                |                        E = DES                           |
|                |                        F = FINAL DES                     |
|                |                        G = EXPEDITE                      |
|                |                                                          |
|                | AP1                  | AP2                               |
|                | Report Line EC:      | Report Line EE:    |Difinition:  |
|                | -------------------- |--------------------|------------ |
|                |      /               |      /             |No Mode Act. |
|                | -------------------- |--------------------|------------ |
|                | 01.1.275.00.11 = 1   | 01.2.275.00.11 = 1 |RUNWAY Mode  |
|                | -------------------- |--------------------|------------ |
|                | 01.1.275.00.12 = 1   | 01.2.275.00.12 = 1 |NAV Mode     |
|                | -------------------- |--------------------|------------ |
|                | 01.1.275.00.13 = 1   | 01.2.275.00.13 = 1 |LOC CAPTURE  |
|                |                      |                    |Mode         |
|                | -------------------- |--------------------|------------ |
|                | 01.1.275.00.14 = 1   | 01.2.275.00.14 = 1 |LOC TRACK    |
|                |                      |                    |Mode         |
```

Value	Content Description		
	01.1.275.00.15 = 1	01.2.275.00.15 = 1	Roll GO AROUND Mode
	01.1.275.00.16 = 1	01.2.275.00.16 = 1	HEADING Mode
	01.1.275.00.17 = 1	01.2.275.00.17 = 1	TRACK Mode
	01.1.274.00.15 = 1	01.2.274.00.15 = 1	PITCH TO Mode
	01.1.274.00.16 = 1	01.2.274.00.16 = 1	PITCH GA Mode
	01.1.274.00.17 = 1	01.2.274.00.17 = 1	V/S Mode
	01.1.274.00.18 = 1	01.2.274.00.18 = 1	FPA Mode
	01.1.274.00.19 = 1 AND 01.1.274.00.20 = 1	01.2.274.00.19 = 1 AND 01.2.274.00.20 = 1	ALT Mode
	01.1.274.00.19 = 1 AND 01.1.274.00.21 = 1	01.2.274.00.19 = 1 AND 01.2.274.00.21 = 1	ALT ACQ Mode
	01.1.274.00.20 = 1 AND 01.1.274.00.22 = 1	01.2.274.00.20 = 1 AND 01.2.274.00.22 = 1	G/S TRACK Mode
	01.1.274.00.21 = 1 AND 01.1.274.00.22 = 1	01.2.274.00.21 = 1 AND 01.2.274.00.22 = 1	G/S CAPTURE Mode
	01.1.274.00.23 = 1	01.2.274.00.23 = 1	FINAL DES Mode
	01.2.274.00.24 = 1	01.2.274.00.24 = 1	EXPED. Mode
	01.1.146.00.14 = 1	01.2.146.00.14 = 1	LAND TRACK Mode
	01.1.274.00.11 = 1 AND 01.1.274.00.13 = 0 OR	01.2.274.00.11 = 1 AND 01.2.274.00.13 = 0 OR	CLB Mode

Value	Content Description		
	01.1.274.00.14 = 0 OR 01.1.274.00.24 = 0	01.2.274.00.14 = 0 OR 01.2.274.00.24 = 0	
	01.1.274.00.12 = 1 AND 01.1.274.00.13 = 0 OR 01.1.274.00.14 = 0 OR 01.1.274.00.24 = 0	01.2.274.00.12 = 1 AND 01.2.274.00.13 = 0 OR 01.2.274.00.14 = 0 OR 01.2.274.00.24 = 0	DES Mode
	01.1.274.00.11 = 1 AND 01.1.274.00.13 = 1	01.2.274.00.11 = 1 AND 01.2.274.00.13 = 1	IM. CLIMB Mode
	01.1.274.00.12 = 1 AND 01.1.274.00.13 = 1	01.2.274.00.12 = 1 AND 01.2.274.00.13 = 1	IM. DES Mode
	01.1.274.00.11 = 1 AND 01.1.274.00.14 = 1	01.2.274.00.11 = 1 AND 01.2.274.00.14 = 1	OPEN CLB Mode
	01.1.274.00.12 = 1 AND 01.1.274.00.14 = 1	01.2.274.00.12 = 1 AND 01.2.274.00.14 = 1	OPEN DES Mode
	Auto Pilot Status DMU: AP1 printed in report line EC AP2 printed in report line EE		
QA 99	Aircraft Quality Number, Report Stability (00 to 99)		
QE 99	Engine Quality Number, Report Stability (00 to 99)		
EPR 9999	EPR Actual (0.6 to 1.8) Eng 1 param. 7C.1.340.01 Eng 2 param. 7C.2.340.10		
EPRC	EPR Command		

Value	Content Description
9999	(0.6 to 1.8) Eng 1 param. 7C.1.341.01 Eng 2 param. 7C.2.341.10
EGT X999	Selected T495 (Exhaust Gas Temperature) (-80 to 999.9 C) Eng 1 param. 7C.1.345.01 Eng 2 param. 7C.2.345.10
N1 9999	Selected N1 Actual (0 to 120.0 %rpm) Eng 1 param. 7C.1.346.01 Eng 2 param. 7C.2.346.10
N2 9999	Selected N2 Actual (0 to 120.0 %rpm) Eng 1 param. 7C.1.344.01 Eng 2 param. 7C.2.344.10
FF 9999	Engine Fuel Flow (0 to 8500 kg/h) Eng 1 param. 7C.1.244.01 Eng 2 param. 7C.2.244.10
P125 99999	PS125 Static Air Pressure at Position 12.5 (0.0 to 30.000 psia) Eng 1 param. 7C.1.257.01 Eng 2 param. 7C.2.257.10
P25 99999	Total Air Pressure at Position 2.5 (0.0 to 30.000 psia) Eng 1 param. 7C.1.262.01 Eng 2 param. 7C.2.262.10
T25 X999	Selected T25 (-30.0 to 300.0 C) Eng 1 param. 7C.1.263.01 Eng 2 param. 7C.2.263.10
P3 9999	Selected PS3 (0.0 to 550.0 psia) Eng 1 param. 7C.1.264.01 Eng 2 param. 7C.2.264.10

Value	Content Description
T3 X999	Temperature at Position 3 (-89.0 to 700.0 C) Eng 1 param. 7C.1.265.01 Eng 2 param. 7C.2.265.10
P49 99999	Pressure on position 4.9 (1 to 25 psia) Eng 1 param. 7C.1.132.01 Eng 2 param. 7C.2.132.10
SVA 999	Stator Vane Actuator Feedback (0 to 100 %) Eng 1 param. 7C.1.325.01 Eng 2 param. 7C.2.325.10
BAF 999	2.5 bleed Actuator Feedback (0 to 100 %) Eng 1 param. 7C.1.335.01 Eng 2 param. 7C.2.335.10
ACC 999	Active Clearance Control Feedback (0 to 100 %) Eng 1 param. 7C.1.330.01 Eng 2 param. 7C.2.330.10
LP 01	LPT ACC Solenoid Position Bit status 1 = closed Eng 1 param. 7C.1.271.01.17 Eng 2 param. 7C.2.271.10.17
GLE 999	Engine Generator Load (0 to 100 %) Eng 1 param. 29.1.077.01 29.2.077.01 Eng 2 param. 29.1.077.10 29.2.077.10
PD 99	Precooler Inlet Pressure (0 to 50 psi) Eng 1 param. 06F.1.143.01 06F.1.143.10 Eng 2 param. 06F.2.142.10 06F.2.142.01

<table>
<tr><th>Value</th><th>Content Description</th></tr>
<tr><td>TN
X99</td><td>Nacelle Temperature
(-55 to 300 C)
Eng 1 param. 26.1.322.01
26.2.322.01
Eng 2 param. 26.1.322.10
26.2.322.10</td></tr>
<tr><td>P2
99999</td><td>Total Air Pressure at Position 2
(0.0 to 25.000 psia)
Eng 1 param. 7C.1.131.01
Eng 2 param. 7C.2.131.10</td></tr>
<tr><td>T2
X999</td><td>T2 Temperature
(-80 to 90.0 C)
Eng 1 param. 7C.1.130.01
Eng 2 param. 7C.2.130.10</td></tr>
<tr><td>ECW1
XXXXX</td><td>Engine Control Word 1
Each 'X' represents 4 Bits in hexadecimal code of a defined ARINC 429 word:
XXXXX Bits HEX
|||||___________ 14, 13, 12, 11 0...F
||||____________ 18, 17, 16, 15 0...F
|||_____________ 22, 21, 20, 19 0...F
||______________ 26, 25, 24, 23 0...F
|_______________ 29, 28, 27 0...7

Bit Label Parameter Description
11 7C.X.270.XX.17 = 1 Manual Thrust Mode Active
12 7C.X.270.XX.18 = 1 N1 Rated Mode Engaged
13 7C.X.270.XX.20 = 1 Auto Thrust Mode Actuvated
14 7C.X.270.XX.21 = 1 2.5 Bleed Failed
15 7C.X.270.XX.23 = 1 Autothrust TLA Limited
16 SPARE
17 SPARE
18 7C.X.270.XX.27 = 1 SVA Failed
19 7C.X.271.XX.16 = 1 FDV Off
20 SPARE
21 7C.X.271.XX.19 = 1 7th Bleed #1 Solenoid Closed (4020KS3)
22 7C.X.271.XX.20 = 1 7th Bleed #2 Solenoid Closed (4020KS1)
23 7C.X.271.XX.21 = 1 10th Bleed Solenoid Closed</td></tr>
</table>

```
+---------------------------------------------------------------------------+
| Value          |                Content Description                       |
|----------------|----------------------------------------------------------|
|                |   24  7C.X.271.XX.28 = 1   P2/T2 Probe Heater Relay       |
|                |                            On                             |
|                |   25  7C.X.351.XX.14 = 1   Left ADC Link Failed           |
|                |   26  7C.X.351.XX.15 = 1   Right ADC Link Failed          |
|                |   27  SPARE                                               |
|                |   28  SPARE                                               |
|                |   29  SPARE                                               |
|----------------|----------------------------------------------------------|
|  ECW2          |   Engine Control Word 2                                   |
|  XXXXX         |   Each 'X' represents 4 Bits in hexadecimal code of       |
|                |   a defined ARINC 429 word:                               |
|                |   XXXXX            Bits                 HEX               |
|                |   |||||___________ 14, 13, 12, 11       0...F             |
|                |   ||||____________ 18, 17, 16, 15       0...F             |
|                |   |||_____________ 22, 21, 20, 19       0...F             |
|                |   ||______________ 26, 25, 24, 23       0...F             |
|                |   |_______________     29, 28, 27       0...7             |
|                |    ------------------------------------------             |
|                |   Bit Label                 Parameter Description         |
|                |   11  7C.X.272.XX.22 = 1   Bleed Config. K1 Selected      |
|                |   12  7C.X.272.XX.23 = 1   Bleed Config. K2 Selected      |
|                |   13  7C.X.272.XX.24 = 1   Bleed Config. K3 Selected      |
|                |   14  7C.X.272.XX.25 = 1   Bleed Config. K4 Selected      |
|                |   15  7C.X.272.XX.26 = 1   Bleed Config. K5 Selected      |
|                |   16  7C.X.272.XX.27 = 1   Bleed Config. K6 Selected      |
|                |   17  7C.X.272.XX.28 = 1   Bleed Config. Data Failed      |
|                |   18  SPARE                                               |
|                |   19  7C.X.272.XX.19 = 1   Bump Mode is selected          |
|                |   20  7C.X.272.XX.20 = 1   Bump Mode is selected          |
|                |   21  7C.X.272.XX.21 = 1   Bump Mode is selected          |
|                |   22  SPARE                                               |
|                |   23  SPARE                                               |
|                |   24  SPARE                                               |
|                |   25  SPARE                                               |
|                |   26  SPARE                                               |
|                |   27  SPARE                                               |
|                |   28  SPARE                                               |
|                |   29  SPARE                                               |
|----------------|----------------------------------------------------------|
|  EVM           |   Engine Vibration Status Word                            |
|  XXXXX         |   Eng 1 param. 3D.1.035.01                                |
|                |   Eng 2 param. 3D.1.035.10                                |
|                |   Each 'X' represents 4 Bits in hexadecimal code of       |
|                |   a defined ARINC 429 word:                               |
```

Value	Content Description
	XXXXX Bits HEX |||||___________ 14, 13, 12, 11 0...F ||||____________ 18, 17, 16, 15 0...F |||_____________ 22, 21, 20, 19 0...F ||______________ 26, 25, 24, 23 0...F |_______________ 29, 28, 27 0...7
OIP 999	Engine Oil Pressure (0 to 400 psia) Eng 1 param. 26.1.317.01 26.2.317.01 Eng 2 param. 26.1.317.10 26.2.317.10
OIT X99	Engine Oil Temperature (-60 to 250 C) Eng 1 param. 26.1.316.01 26.2.316.01 Eng 2 param. 26.1.316.10 26.2.316.10
OIQH X999	Oil Consumption from the previous flight (-9.99 to 20.00 qts/h)
VB1 999	N1 Vibration (0 to 10.0) Eng 1 param. 3D.1.135.01 Eng 2 param. 3D.1.135.10
VB2 999	N2 Vibration (0 to 10.0) Eng 1 param. 3D.1.136.01 Eng 2 param. 3D.1.136.10
PHA 999	FAN Pick Up Phase Angle (0 to 360 deg) Eng 1 param. 3D.1.226.01 Eng 2 param. 3D.1.226.10
WFQ 99999	Fuel Quantity Inner Cell (0 to 99999 kg) param. 5A.2.257.10 Left Inner Cell param. 5A.2.261.19 Right Inner Cell

Value	Content Description
ELEV X999	Elevator Position (-30 to 15 deg) param. 6C.1.314.01 Left Elevator Position param. 6C.2.314.10 param. 6C.1.334.01 Right Elevator Position param. 6C.2.334.10
AOA X999	Corrected Angle of Attack (-30 to 85 deg) param. 06.1.241.01 AOA System 1 param. 06.2.241.10 AOA System 2
SLP X999	Side Slip Angle (-32.0 to 32.0 deg) param. 0A.1.226.00 System 1 param. 0A.2.226.00 System 2
CFPG X9999	Side Slip Angle (-0.9999 to 4.0000 g)
CIVV X999	Calculated Inertial Vertical Speed (-999 to 999 ft/min)
RUDD X999	Rudder Position (-30.0 to 30.0 deg) param. 29.1.312.00 param. 29.2.312.00
RUDD X999	Rudder Trim Position (-25.0 to 25.0 deg) param. 0A.1.313.00 param. 0A.2.313.00
AILL X999	Left Aileron Position (-25.0 to 25.0 deg) param. 6C.1.310.01 param. 6C.2.310.10
AILR X999	Right Aileron Position (-25.0 to 25.0 deg) param. 6C.1.330.01 param. 6C.2.330.10

Value	Content Description
STAB X999	Stabilizer Position #1 (-13.5 to 4.0 deg) param. 6C.1.315.01 param. 6C.2.315.10
ROLL X999	Roll Angle (-90.0 to 90.0 deg) param. 04.1.325.01 param. 04.2.325.10
YAW X999	Body Axis Yaw Rate (-45.0 to 45.0 deg/sec) param. 04.1.330.01 param. 04.2.330.10
RSP2 X999	Roll Spoiler 2 Position (-45.0 to 0 deg) param. 6C.1.362.01 Left Spoiler param. 6C.2.362.10 param. 6C.1.372.01 Right Spoiler param. 6C.2.372.10
RSP3 X999	Roll Spoiler 3 Position (-45.0 to 0 deg) param. 6C.1.363.01 Left Spoiler param. 6C.2.363.10 param. 6C.1.373.01 Right Spoiler param. 6C.2.373.10
RSP4 X999	Roll Spoiler 4 Position (-45.0 to 0 deg) param. 6C.1.364.01 Left Spoiler param. 6C.2.364.10 param. 6C.1.374.01 Right Spoiler param. 6C.2.374.10
RSP5 X999	Roll Spoiler 5 Position (-45.0 to 0 deg) param. 6C.1.365.01 Left Spoiler param. 6C.2.365.10 param. 6C.1.375.01 Right Spoiler param. 6C.2.375.10
FLAP	Flap Actual Position

Value	Content Description
X999	(-9.0 to 40.0 deg) param. 1B.1.137.01 System 1 param. 1B.2.137.10 System 2
SLAT X999	Slat Actual Position (-9.0 to 27.0 deg) param. 1B.1.127.01 System 1 param. 1B.2.127.10 System 2
THDG X9999	True Heading (BCD) (0 to 359.9 deg) param. 04.1.044.01 System 1 param. 04.2.044.10 System 2
LONP X9999	Longitude Position (East 179.9 deg to West 179.9 deg) param. 04.1.311.XX System 1 param. 04.2.311.XX System 2
LATP X9999	Latitude Position (North 89.9 to South 89.9 deg) param. 04.1.310.XX System 1 param. 04.2.310.XX System 2
WS 999	Wind Speed (0 to 100 kts) param. 04.1.315.01 System 1 param. 04.2.315.10 System 2
WD 999	WIND Direction - True (0 to 359 deg) param. 04.1.316.01 System 1 param. 04.2.316.10 System 2
FT X999	Fuel Temperature (-60.0 to 170.0 C) param. 5A.2.177.10 Fuel Temp. Left Wing Tank param. 5A.2.201.10 Fuel Temp. Right Wing Tank
FD 0999	Fuel Temperature (0 to 0.999 kg/l) param. 5A.2.272.10

(2) Cruise Performance Report Logic (Engine Type IAE)

Code No.	Item No.	Description of Function Item	Progr. MCDU GSE	Standard Value or Table TXY
	A	Report Format		
	B	Parameter Table		
	C	First three lines of Report	C	Blank
	D	Print Out Rules	C	2
	E	Transfer to ACARS MU	C	No
	F	Increment of the report counter if the report was triggered by a code number > 1000; 1=yes, 0=no	C	1
	G	Averange intervales in seconds	AI	20
	H	Overall Average of 'F02' averages	AI	5
	I	OIQ values taken from 'taxi out' used for QIQH calculation the same programming as for Report <01> is apply.		
1000	1	Manual selection via MCDU		
2000	2	Flight phase dependent manual selection via remote print button if programmed.		
	2.1	Logic algorithm		
	2.2	Remote Print Button assignment	C	not
3000	3	Programmable Start Logic		
	3.1	Logic algorithm	C	
	3.2	Trigger condition	C	not
5000		The DMU generates the Cruise Performance Report based on 'Flight Hours' or 'Flight Legs' programmable via GSE. Logic based on Flight Hours: During a time frame of 'Y02.1' flight hours the DMU search in flight phase 6 for report generation with stable frame criteria where the best aircraft quality number QA is calculated. The report with the best quality number QA is stored in the report buffer:		

Code No.	Item No.	Description of Function Item	Progr. MCDU GSE	Standard Value or Table TXY
		Logic based on Flight Legs:		
		Every 'Y02.2' flight legs the DMU search in flight phase 6 for report generation with stable frame criteria where the best aircraft quality number QA is calculated. The report with the best quality number QA is stored in the report buffer.		
	5	The default programming is 'Flight Legs'	C	Legs
	5.1	Logic algorithm		
	5.2	'Y02.1' flight hours	C	T24/T25
	5.3	'Y02.2' flight legs	C	T24/T25
	5.4	'P02' stable periods (5 subperiods = 100 sec)	C	T24/T25
	5.5	78% < ACC < 100% param. 7C.1.330.01 Eng.1 param. 7C.2.330.10 Eng.2		
		Stable frame conditions: During 'P02' seconds the following parameters are stable as defined below:		
		The stable frame variation is customer programmable, but only in the range defined in the column for standard values.		
	5.6	IALT 04.1.361.-- ft 04.2.361.--	AI	T24/T25
	5.6.1	WA of IALT	C	T24/T25
	5.7	GS 04.1.312.01 kts 04.2.312.10	AI	T24/T25
	5.7.1	WA of GS	C	T24/T25

Code No.	Item No.	Description of Function Item	Progr. MCDU GSE	Standard Value or Table TXY
	5.8	ROLL ANGLE 04.1.325.01 degr. 04.2.325.10	AI	T24/T25
	5.8.1	WA of ROLL ANGLE	C	T24/T25
	5.9	TAT 06.1.211.01 C 06.2.211.10	AI	T24/T25
	5.9.1	WA of TAT	C	T24/T25
	5.10	N2 7C.1.344.01 Eng.1 % 7C.2.344.10 Eng.2	AI	T24/T25
	5.10.1	WA of N2	C	T24/T25
	5.11	EGT 7C.1.345.01 Eng.1 C 7C.2.345.10 Eng 2	AI	T24/T25
	5.11.1	WA of EGT	C	T24/T25
	5.12	VACC 04.1.364.01 g 04.2.364.10	AI	T24/T25
	5.12.1	WA of VACC	C	T24/T25
	5.13	MN 06.1.205.01 Mach 06.2.205.10	AI	T24/T25
	5.13.1	WA of MN	C	T24/T25
	5.14	N1 7C.1.346.01 Eng.1 % 7C.2.346.10 Eng.2	AI	T24/T25
	5.14.1	WA of N1	C	T24/T25
	5.15	PT2 7C.1.131.91 Eng.1 psia 7C.2.131.10 Eng.2	AI	T24/T25
	5.15.1	WA of PT2	C	T24/T25
	5.16	FF 7C.1.244.01 Eng.1 kg/h 7C.2.244.10 Eng.2	AI	T24/T25
	5.16.1	WA of FF	C	T24/T25
	5.17	EPR 7C.1.340.01 Eng.1 % 7C.2.340.10 Eng.2	AI	T24/T25
	5.17.1	WA of EPR	C	T24/T25
8100	8.1	ACARS MU uplink request with IMI 'REQ02'		

Code No.	Item No.	Description of Function Item	Progr. MCDU GSE	Standard Value or Table TXY
		The report <02> is immediately generated and transmitted to the ACARS MU.		
8200	8.2	ACARS MU uplink request with IMI 'G02' The report <02> is generated as soon as stable frame criteria are met, i.e. the DMU is immediately start searching for stable frame criteria independing from any other logic.		
AI = Programmable by Airbus Industrie C = Programmable by Customer				

M. Engine Take-Off Report <04>
(Ref. Fig. 013, 014)
The Engine Take-Off Report is an average data collection of aircraft and engine around the point of peak N1 while in take-off flight phase.
The engine take-off report, is generated when one of the logic conditions 1000 to 5009 (for details see engine take-off report logic) is present.
Each Take-Off Report is contain a T/O delta N1 respective EPR summary.

(1) Engine Take-Off Report Data Field Description (Engine Type IAE)

Value	Content Description
ESN 999999	Engine Serial Number (000000 to 999999) Eng 1 param. 7C.1.046.01 digit 3, 2, 1 7C.1.047.01 digit 6, 5, 4 Eng 2 param. 7C.2.046.01 digit 3, 2, 1 7C.2.047.01 digit 6, 5, 4
EHRS 99999	Engine Flight Hours (00000 to 99999 hours) DMU Engine 1 and Engine 2
ERT 99999	Engine Running Time (00000 to 65536 hours) Eng 1 param. 7C.1.050.01 Eng 2 param. 7C.2.050.10

6. APPENDIX 6 - AUDITING AIRCRAFT CRUISE PERFORMANCE IN AIRLINE REVENUE SERVICE

The following pages are a copy of the article that was distributed during the 7th Performance and Operations Conference held at Cancun, Mexico in year 1992. This brochure is based upon the leading article “Auditing aircraft cruise performance in airline revenue service” presented by Mr. J.J. SPEYER, which was used as reference material.

AIRBUS INDUSTRIE
Engineering Directorate
Flight Division

Auditing aircraft cruise performance in airline revenue service

1. Introduction

For many years the subject of aircraft performance monitoring has been emphasized or de-emphasized according to fluctuations in fuel prices. Although at times a reduced interest in fuel conservation could be noted, even relatively low fuel prices still make this cost item a rather expensive commodity. Today, in our era of economic disarray, airlines are again becoming very prone to checking the fuel efficiency of their fleets.

Since the early 1980s several meetings and symposia on fuel conservation and performance assessment have been held through the world. Airbus Industrie, for its part, extensively addressed the subject at the 1984 in Cannes organized a specific symposium on Performance and Monitoring at the 1985 Operators' Conference in Bangkok. The time has come to report further on progress made since then.

The purpose of this paper is therefore to provide a comprehensive review of how Airbus Industrie proceeds with auditing cruise performance in airline operations. This will cover measurement procedures, precautions and dataprocessing methods. It will also provide more information (statistics, techniques and case studies) on various environmental, operational and technical effects which contribute to performance bias and measurement scatter, and which need to be corrected for meaningfull comparisons with the aircraft baseline. A sharp focus on trends, rather than aiming for absolute measurements, will be underlined with several examples. All bias and scatter effects will also be documented and referenced with industry - manufacturers and airlines - actions and situation reports.

2 . Measurement procedures

2.1 Specific Range Method

2.1.1 General Principle

Data recorded in flight is used to generate a measured Specific Range (SR or nautical miles produced per pounds of fuel invested). This is then compared to the SR predicted by the In-Flight Programme (IFP) for the given flight conditions (weight, altitude, TAT, Mach). In addition to the specific range deviation (DSR), the Aircraft Performance Monitoring program (APM) also provides:

- deviations of N_1 (or EPR) required to fly from nominal, i.e. DN $_{1(1,2)}$ (or DEPR $_{(1,2)}$),

- deviations of fuel flow (FF) from nominal for engine 1 ($N_{1,1}$ or EPR_1) (DFF_{11}) and for engine 2 (N_{12} or EPR_2) (DFF_{12})

- deviations of fuel flow (FF) from nominal at given CL for engine 1 (DFF_{21}) and for engine 2 (DFF_{22})

  This technique provides the **apparent** ability to discern respective engine and airframe contributions to an observed performance deviation.

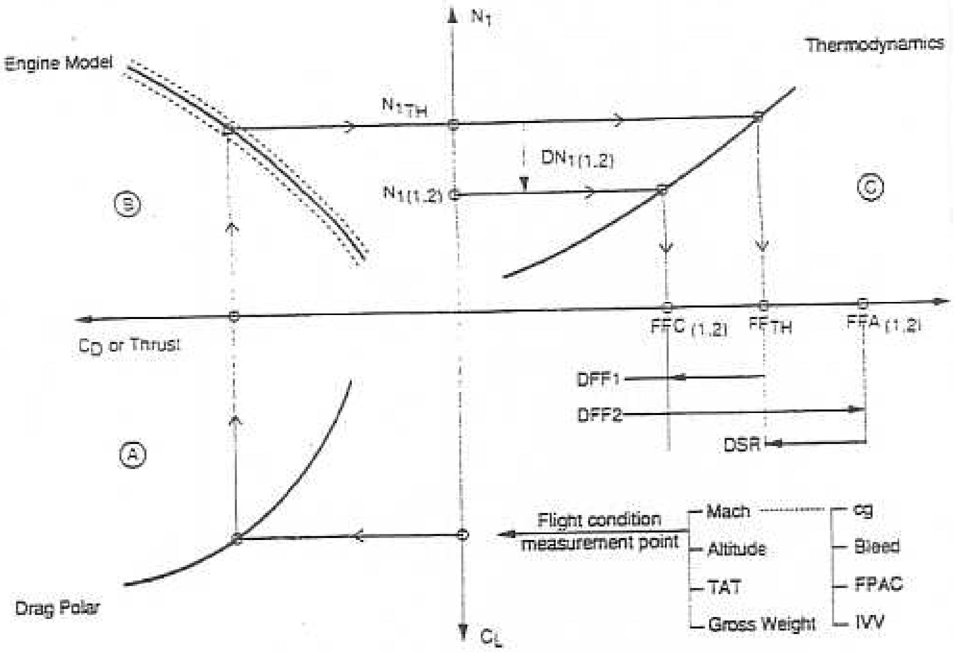


Figure 1

APM Programme Results

DFF_{11}	=	$(FFC_1 - FF_{TH})/FF$	x	100 (%)
DFF_{12}	=	$(FFC_2 - FF_{TH})/FF_{TH}$	x	100 (%)
DFF_{21}	=	$(FFA_1 - FFC_1)/FFC_1$	x	100 (%)
DFF_{22}	=	$(FFA_2 - FFC_2)/FFC_2$	x	100 (%)
DSR	=	$(2FF_{TH} - FFA_1 - FFA_2) / (FFA_1 + FFA_2)$ x 100 (%)		
DN_1	=	$(DN_{11} + DN_{12}) / 2$	Aerodynamic related part	(x 100 (%))
DFF_1	=	$(DFF_{11} + DFF_{12}) / 2$		
DFF_2	=	$(DFF_{21} + DFF_{22}) / 2$ -	Engine related part	(x 100 (%))
DSR	=	$- (DFF_1 + DFF_2)$	Specific Range related(reciprocal of addition of both parts)	(x 100 (%))

Two aspects need to be underlined to appreciate the results of the APM programme :

1) **The thrust / drag uncertainty**
   C_L at flight condition for a measurement point corresponds to C_D through the drag polar (quadrant Ⓐ; thrust is to compensate drag and is related to N_1 (quadrant Ⓑ) with the possibility of engine-to-engine model alteration (N_1 (EPR)/thrust relationship).

2) **engine-to-engine model N_1 (EPR) / thrust relationship** alterations whereby DFF_1 - aerodynamic part - (quadrant ©) may shift.

- an observed ΔN_1 or ΔEPR does not necessarily indicate an aerodynamic deterioration of the airframe. An altered N_1 / thrust or EPR / thrust relationship with respect to the reference engine is, in many cases, responsible for such a deviation. This is also valid for new engines as well. Engine test-cell-gathered N_1 or EPR versus thrust ratios cannot be transmitted to cruise high Mach / high altitude conditions with an acceptable confidence level.

- With the A310 / A300-600 an energy correction was added to the APM to take into account variations in kinetic (FPAC - acceleration / deceleration) and potential energy (inertial vertical velocity). This reduces the scatter of the APM results but is only valid for small movements respecting the stabilization criteria expressed in 2.1.3. And boils down to remain in the linearized part of the equations of movement programmed into the APM.

Note : No FPAC / IVV, C.G. corrections taken into account in the A300B2 / B4 program.

2.1.2 . Measurement procedures and precautions

Figure 2 shows a sample recording form used for hand recordings.

Prior to take-off

- Calculate fuel on board at MES (Main Engine Start) by taking remaining fuel + truck uplift (measured at truck) accounting for actual fuel density, on-board fuel quantity indication system is generally less accurate than truck dispenser (better than 0.1 %)

- Determine ZFW and take-off C.G. (loadsheet, pax weight recalculation; etc)
- Note APU running time since MES
- Compute APU fuel consumption to amend FU (since it is not measured)

In flight

- Verify aircraft flying in cruise on a straight leg of at least 15 minutes
- Perform fuel balancing if imbalance between exists tanks inner: 400 kg, center : 100 kg
- Trim aircraft longitudinally (AP disconnect)
- Apply ZCW trim procedure (FCOM 2.02.09 for A310 / A300-600) to put aircraft (A310 / A300-600) in best cruise condition, (WLV subsequently if there is a need for asymmetry diagnosis to determine extra drag).

- If data are taken on a long-range flight, it is recommended to collect data at different gross weight/altitude combinations if possible (High GW - low altitude at the beginning of the flight, Low GW - high altitude at the end of the flight).

- Disconnect autothrottle and set N_1 (EPR) at appropriate value (GW, Mach, ALT, SAT)
- Do not touch the throttles during the whole subsequent period unless readings are stopped because of instability
- Select autopilot in ALT HLD / HDG SEL
- Note air conditioning mode on A310 / A300-600 (N or E); select N air conditioning mode on A320
- Allow 4 minutes for aircraft stabilization before starting to take readings (take EGT, ground speed and SAT as references)
- Respect the following stability criteria :

ΔZ_P **+ 20 ft**

Δ **SAT** $\leq \pm 1°C$

$\frac{\Delta GS}{\Delta t} \leq \pm$ **1kt / minute** (readings every 15 / 30 seconds)

Δ **Mach** $\leq \pm$ **0.003**

- aim for low drift angles if possible : the initial drift angle should be less than 5 degrees and the drift angle change should not exceed 0.5 degrees / minute.

- record data for at least 6 minutes if favourable stability conditions are maintained
- start cruise performance readings by filling-in the adjacent cruise performance recording form in Figure 2
- respect the following sampling rates :

Parameter	Note at intervals of	Parameter	Note at intervals of
- Altitude (Z_P)	60 seconds	- Fuel flow (FF)	60 seconds
- Mach (M) / TAS	60 seconds	- EGT	60 seconds
- TAT / SAT	60 seconds	- Fuel used (FU)	1 minute
- N_1 (or EPR)	60 seconds	- Ground speed (GS)	15 - 30 seconds

- Note also latitude or station approaching, drift, heading, wind velocity / direction, track / course for calculation of effects to be mentioned in section 3.
- Do not forget to consult weather charts (forecasts and actuals) to confirm pressure patterns
- Do not omitt to mention TCCS / ARCCS on or off (if installed), trim values (ZCW or WLV), C.G., air conditioning mode
- do not omit to note tail number, date, flight sector for referencing.

Notes

1) A suspected airframe deterioration resulting from an observed ΔN_1 or ΔEPR should be confirmed by verified (visible) aerodynamic drag / airflow disturbance sources such as misrigging, dents, missing seals, steps, gaps, etc.

2) Therefore, conduct a visual inspection (extended walkaround) of the aircraft noting any possible aerodynamic discrepancies and possibly confirming these by photographs. Also do this in flight, should a visual observation of the (upper) wing surfaces be performed (slats, spoilers, flaps, ailerons) and pictures be taken (zoom photographs).

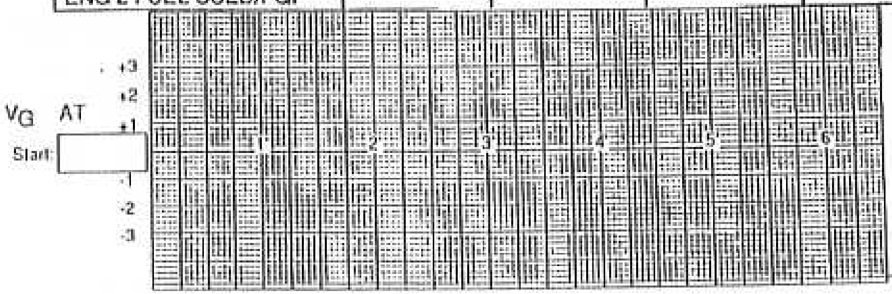
3) Aircraft asymmetry drag diagnosis can be performed using the ZCW / WLV technique (FCOM 2.02.09 for A310 / A300-600).

4) Mach changes during high altitude cruise result in compressibility effects aerodynamically influencing longitudinal trimming of the aircraft.

A310/A300-600 cruise performance records

RAMP WT AT MES ________ kg APU running time since MES____ Air conditioning : E or N	LAT or STATIONS Autopilot : c.g. (T/O)	Drift : HDG : W/V : Track/course :	Date : Flight : Sector : Aircraft :	ATS off TCCS ON OFF

UTC		START	1'	2'	3'	4'	5'	6'
	EGT							
ADC 1 and/or ADC 2	ALT							
	M / TAS							
	TAT / SAT							
ENG 1 N1 (or EPR)								
ENG 2 N1 (or EPR)								
ENG 1 FUEL FLOW								
ENG 2 FUEL FLOW								
ENG 1 FUEL USED:FQI								
ENG 2 FUEL USED/FQI								



STAB. CRITERIA
(during 6 min)

$\Delta ZP \leq \pm 20$ ft
$\Delta SAT \leq \pm 1°C$
$\frac{\Delta GS}{\Delta t} \geq \pm 1$ kt/min

Control wheel CM1 CM2

Aileron :
Rudder : NR/NL
Horizontal stab . :
ZCW or WLV
Inclinometers :
ϕ WLeft/right :

Figure 2

2.1.3 Data analysis procedure

Based on the in-flight recorded data, aircraft stability will be assessed from the ground speed trend. The most representative portions of a 6-minute run will be selected (one, two or more overlapping if data is good). Stability criteria (cf. 2.1.2) are to guide the choice, the best case being a fully flat trend.

Basic inputs into the APM will be the following :

- **Zp, M, TAT, N1 (or EPR) and FF averaged over selected best 3-minute frames**
- **GW** which will be based on ramp weight at MES, and FU at center point of selected 3-minute frames,
- **C.G.** which will be calculated from take-off C.G, and fuel burn schedule (or from the ECAM if applicable from CGCC)
- **Aircraft acceleration along flight path (FPAC)** which will be the slope (linear regression) of ground speed over the 3-minute frames; **the same applies for the vertical speed but sloped through altitude**
- **LHV, latitude, heading** are introduced to take into account fuel calorific content and Coriolis / centrifugal and local gravity effects respectively as discussed in section 3.

Notes

1) The APM program incorporates a statistical outlier elimination : the mean and standard deviations are being calculated for each programme result column (DN_{11}, DN_{12}, DFF_{11}, DFF_{12}, DFF_{21}, DFF_{22}, DSR). Whenever a measurement point result is outside the 95% confidence interval ($\mu - 2\sigma$, $\mu + 2\sigma$) it is eliminated (noted as "-") and not included in the final column mean value and standard deviation ; whenever a measurement point result give at least one "-", another APM run should be performed with the measurement point deleted altogether from the input file.

   This is to be performed until convergence to outputs without "-" and should alleviate scatter and help to better verify DSR = - (DFF_1 + DFF_2).

2) A real case example is shown in Figure 3 with associated APM outputs available in Figure 5. The three selected frames meeting the stability criteria were averaged (Figure 4) and then input into the APM.

3) The application of the FPAC correction effectively reduces scatter . An uncorrected FPAC of 1kt/minute corresponds to a drag deviation of approximately 1.3 %.

A310/A300-600 cruise performance records

RAMP WT AT MES 140 636 kg
APU running time since MES 5'
Air conditioning : E or N

LAT or N 45°00'
STATIONS W 22°57'
Autopilot : AP2
c.g. (T/O) = 36.5%

Drift : 2L
HDG : 127°
W/V : 269°/35 kts
Track/course : 125°

Date : 21/6/90
Flight : ABC 123
Sector : YMX-LIS
Aircraft : A310-300

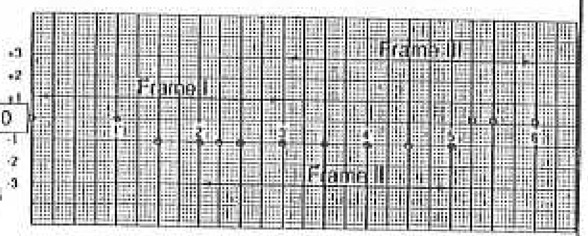
ATS OFF
TCCS ON
OFF

UTC		START 03 h 23	1' 03 h 24	2' 03 h 25	3' 03 h 26	4' 03 h 27	5' 03 h 28	6' 03 h 29
	EGT	636 / 624	634 / 626	634 / 626	634 / 626	638 / 626	638 / 626	640 / 628
ADC 1 and/or ADC 2	ALT	36885 / 36990	36875 / 36990	36880 / 36985	36975 / 36985	36980 / 36990	36975 / 36985	36980 / 36990
	M / TAS	.802/.808 462/464	.803/.809 462/464	.801/.807 461/463	.799/.803 458/461	.795/.800 456/459	.795/.800 456/459	.794/.799 457/459
	TAT / SAT	- 59/- 28	- 56/- 28	- 57/- 29	- 56/- 29	- 56/- 29	- 56/- 29	- 56/- 29
ENG 1 N1 (or EPR)		90.1	90.2	90.2	90.2	90.2	90.2	90.3
ENG 2 N1 (or EPR)		90.0	90.1	90.1	90.1	90.1	90.1	90.2
ENG 1 FUEL FLOW		2080	2085	2080	2080	2080	2080	2080
ENG 2 FUEL FLOW		2070	2075	2065	2065	2065	2065	2075
ENG 1 FUEL USED:FQI		10950	10990	11020	11060	11020	11130	11150
ENG 2 FUEL USED/FQI		10900 (12800)	10940	10980 (12600)	11010	10980 (12600)	11090 (12600)	11110

Va AT

Start 490

FRAME I : FPAC = - 0.00044
FRAME II : FPAC = - 0.00022
FRAME III : FPAC = + 0.00044



STAB. CRITERIA
(during 6 min)

$\Delta ZP \leq \pm 20$ ft
$\Delta SAT \leq \pm 1°C$
$\frac{\Delta GS}{\Delta t} \geq \pm 1$ kt/min

Control wheel CM1 CM2

Aileron : 0.4 LWD 0.5 LWD
Rudder : NR/NL
Horizontal stab. : 0.9 +
ZCW or WLV
Inclinometers : 0
ϕ WLeft/right : 0

Figure 3

2.1.4 Results appraisal

Taking into account the remarks (2.1.2) concerning possible N_1 (or EPR) / thrust relationship alterations, the following possibilities exist :

1) a) **DN_{11} and $DN_{12} > 0$ and thus DFF_{11} and $DFF_{12} > 0$**
which means $DFF_1 > 0$, i.e.
higher apparent drag (or lower thrust at N1) than model
or

b) **DN_{11} and $DN_{12} < 0$ and thus DFF_{11} and $DFF_{12} < 0$**
which means $DFF_1 < 0$, i.e.
lower apparent drag (or higher thrust at N_1) than model

2) a) **DFF_{21} and/or $DFF_{22} > 0$**
which means **higher fuel consumption than model**

b) **DFF_{21} and/or $DFF_{22} < 0$**
which means **lower fuel consumption than model**

Data analysis procedure

Averages for the three frames

	I	II	III
EGT	638/626	638/626	638/627
ALT	36879/36787	36977/36987	36977/36987
MACH	.801/.807	.798/.803	.796/.801
SAT/TAT	-56.2/-28.2	-56.7/-29	-56/-25
N_{11}/N_{12}	90.18/90.08	90.2/90.1	90.23/90.13
ff_1/ff_2	2081/2069	2080/2065	2080/2068
FU	21962	22107	22172
N - air conditioning			
CG	= 36.4	= 36.4	= 36.4
FPAC	= - 0.00044	= - 0.00022	= + 0.00044
V.V.	= - 0.4	= - 0.4	= - 0.4
WLV - trimming			
GW_i	= 118.757	= 118.612	= 118.747

Figure 4

```
*** A I R B U S   C R U I S E   P E R F O R M A N C E * A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G (APM) ***
                                  *** PROGRAM : APMPC 11.2 ***

*** ENGINE SER.NO. L :              *** DATA BASE :                                                                ***
*** ENGINE SER.NO. R :                  AERO    A310-304   FROM  28/02/87  / GENERAL A310-304-01  FROM  30/03/86   ***
*** TAIL-NUMBER :                       ENGINE  A310-304   FROM  25/04/90    TYPE      CF6-80C2A2                  ***
```

NO	DATE	FLNO	CASE	ALT FEET	TAT C	MACH	WEIGHT KG	CG %	FPAC G	VV FT/MIN	THDG DEG	LAT DEG	VWI KTS	DWI DEG	ACT. W. N
1	210690	303	1	37040.	-29.7	.806	121909.	36.1	.0000	1.2	----	----	----	----	1195519.
2	210690	303	2	37041.	-29.7	.806	121837.	36.1	.0000	1.2	----	----	----	----	1194813.
3	210690	303	3	37047.	-29.7	.805	121694.	36.1	.0000	1.2	----	----	----	----	1193411.
4	210690	303	4	36984.	-30.0	.803	120219.	36.6	.0004	.0	----	----	----	----	1178946.
5	210690	303	5	36984.	-29.7	.803	120147.	36.6	.0003	.0	----	----	----	----	1178240.
6	210690	303	6	36935.	-29.0	.801	119254.	36.3	.0000	.0	----	----	----	----	1169482.
7	210690	303	7	36935.	-28.7	.803	119177.	36.3	.0003	.0	----	----	----	----	1168727.
8	210690	303	8	36934.	-28.7	.803	119107.	36.3	.0002	.0	----	----	----	----	1168041.
9	210690	303	9	36933.	-28.2	.804	118757.	36.4	-.0004	-.4	----	----	----	----	1164608.
10	210690	303	11	36932.	-29.0	.799	118547.	36.4	.0004	-.4	----	----	----	----	1162549.

```
*** A I R B U S   C R U I S E   P E R F O R M A N C E * A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G (APM) ***
                                  *** PROGRAM : APMPC 11.2 ***

*** ENGINE SER.NO. L :              *** DATA BASE :                                                                ***
*** ENGINE SER.NO. R :                  AERO    A310-304   FROM  28/02/87  / GENERAL A310-304-01  FROM  30/03/86   ***
*** TAIL-NUMBER :                       ENGINE  A310-304   FROM  25/04/90    TYPE      CF6-80C2A2                  ***
```

NO	BL	WBL1	WBL2	N11	N12	FFA1	FFA2	FLHVR	N1TH	FFTH	FF1	FF2	DN11	DN12	DFF11	DFF12	DFF21	DFF22	DSR
		--- KG/S ---		---- % -----		--- KG/H ---			%	------ KG/H -------			---------------- % ----------------						
1	N	----	----	90.6	90.5	2122.	2114.	.999	91.1	2117.	2077.	2069.	-.44	-.54	-1.85	-2.27	2.14	2.19	-.07
2	N	----	----	90.6	90.5	2122.	2112.	.999	91.1	2118.	2077.	2068.	-.47	-.57	-1.95	-2.37	2.18	2.14	.04
3	N	----	----	90.7	90.6	2127.	2115.	.999	91.0	2110.	2079.	2071.	-.36	-.44	-1.50	-1.84	2.33	2.10	-.51
4	N	----	----	90.1	90.1	2081.	2086.	.999	90.6	2082.	2033.	2033.	-.55	-.55	-2.35	-2.35	2.36	2.61	-.08
5	N	----	----	90.2	90.2	2087.	2089.	.999	90.6	2079.	2038.	2038.	-.47	-.47	-2.01	-2.01	2.43	2.33	-.41
6	N	----	----	90.2	90.1	2081.	2066.	.999	90.4	2050.	2030.	2024.	-.23	-.30	-.98	-1.26	2.51	2.06	-1.13
7	N	----	----	90.2	90.1	2081.	2066.	.999	90.6	2067.	2034.	2026.	-.38	-.48	-1.61	-2.01	2.32	1.99	-.30
8	N	----	----	90.2	90.1	2081.	2066.	.999	90.6	2069.	2038.	2030.	-.35	-.45	-1.47	-1.87	2.10	1.78	-.23
9	N	----	----	90.2	90.1	2061.	2069.	.999	90.4	2046.	2030.	2022.	-.19	-.29	-.79	-1.19	2.51	2.34	-1.39
10	N	----	----	90.2	90.1	2080.	2068.	.999	90.3	2043.	2032.	2024.	-.12	-.22	-.51	-.92	2.35	2.18	-1.51
										MEAN VALUE			-.36	-.43	-1.50	-1.81	2.33	2.19	-.56
										STANDARD DEVIATION			.14	.12	.58	.51	.14	.25	.57

```
*** 95 % CONFIDENCE :
    THE 5% VALUES OUT OF RANGE (MEAN+- 2*SIGMA) ARE SET TO *** AND ARE NOT INCLUDED IN THE FINAL MEAN VALUE AND STANDARD DEVIATION
```

```
*** A I R B U S   C R U I S E   P E R F O R M A N C E * A I R C R A F T   P E R F O R M A N C E   M O N I T O R I N G (APM) ***
                                  *** PROGRAM : APMPC 11.2 ***

*** ENGINE SER.NO. L :              *** DATA BASE :                                                                ***
*** ENGINE SER.NO. R :                  AERO    A310-304   FROM  28/02/87  / GENERAL A310-304-01  FROM  30/03/86   ***
*** TAIL-NUMBER :                       ENGINE  A310-304   FROM  25/04/90    TYPE      CF6-80C2A2                  ***
```

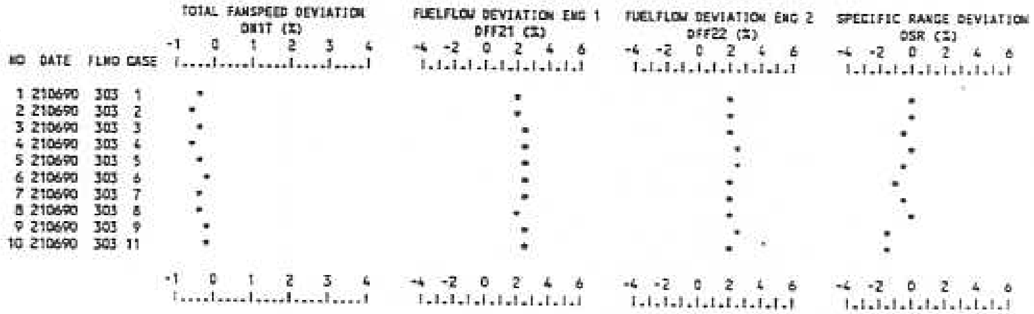


Figure 5

Note

and / or meaning that it is also possible that :

1) $DFF_{21} > 0$ and $DFF_{22} < 0$

① $|DFF_{21}| > |DFF_{22}| \Rightarrow DFF_2 > 0$
excess cons. from engine part

② $|DFF_{21}| < |DFF_{22}| \Rightarrow DFF_2 < 0$
lower cons. from engine part

2) DFF21 < 0 and DFF22 > 0

① $|DFF_{21}| > |DFF_{22}| \Rightarrow DFF_2 < 0$
lower cons. from engine part

② $|DFF_{21}| < |DFF_{22}| \Rightarrow DFF_2 > 0$
excess cons. from engine part

3) Combining 1) and 2) gives the following possibilities with regard to specific range :

a) $DFF_1 > 0$ and $DFF_2 > 0 \Rightarrow DSR < 0$
compounded effect resulting in specific range deviation (worse than book value)

b) $DFF_1 < 0$ and $DFF_2 > 0$:

1) if $|DFF_1| > |DFF_2| \Rightarrow DSR > 0$
higher engine fuel consumption than model is being compensated by an apparently better than nominal aerodynamic condition resulting in better specific range than book value

2) if $|DFF_1| < |DFF_2| \Rightarrow DSR < 0$
partial compensation resulting in worse specific range than book value.

c) $DFF_1 > 0$ and $DFF_2 < 0$:

1) if $|DFF_1| > |DFF_2| \Rightarrow DSR < 0$
partial compensation resulting in worse specific range than book value

2) if $|DFF_1| < |DFF_2| \Rightarrow DSR > 0$
an apparently worse than nominal aerodynamic condition is being compensated by lower engine consumption than model, resulting in better specific range than book value.

d) $DFF_1 < 0$ and $DFF_2 < 0 \Rightarrow DSR > 0$
compounded effect resulting in specific range deviation (better than book value).

Example

Higher engine fuel consumption than model is very often observed and at times is partially compensated by an apparently better-than-nominal aerodynamic condition as exemplified in the APM outputs shown in Figure 5. The three stable points identified from the manual recordings of Figure 3 were processed by APM. Only two of these were retained by the $\pm 2\sigma$ procedure and are framed in Figure 5.

The result of $DFF_1 + DFF_2$ (with $DFF_1 < 0$ and $DFF_2 > 0$ and $|DFF_1| < |DFF_2|$) is a marginal deviation in DSR (-0.56 %).

Notes

1) Up to now, engine modular analysis has been barely capable of supporting aircraft performance monitoring with respect to distinguishing airframe and engine contributors to performance deviations. The main reason for this has been the use of different engine baselines in the APM / IFP (aircraft / engine combination) of Airbus Industrie and in the ECM (engine alone) provided by the engine manufacturer.

2) The Specific Range (SR) method is the most effective procedure to be used in airline practice, but crew complement considerations may pre-empt its use.

3) When in parallel an AIDS or ACMS analysis is performed back-to-back comparisons can be made if the event marker is activated every minute or if the printer can be used in conjunction with manual recordings.

4) Data trends should be performed when assessing APM outputs, as illustrated in section 4.

2.2 Fuel-used (FU) method

2.2.1 General principle

The basis of the FU method is to measure the fuel burnt by the aircraft in level flight and to compare it to the fuel burn prediction of the IFP for the given flight conditions and timespan. If less effective than the SR method, the FU method is certainly less restrictive in terms of stability and data acquisition requirements, the autothrottle being allowed to remain selected.

As an alternative method, it is sufficient to check or prove the accuracy or confidence level of the applied flight planning method since it accounts for all operational factors such a ATS on, CG movements, aircraft manoeuvering, flight path and vertical accelerations, weather influences, etc. As an alternative performance monitoring tool the FU - method offers also the possibility of mutual validation with the SR - method.

The SR method is based on a short timespan measurement that needs to satisfy stringent criteria, the FU method relies an a long timespan measurement that is very flexible in terms of data acquisition requirements. Although it is more easily integrated into daily cockpit recording, the efficiency of this method (result to effort ratio) is not very high. Due to the relatively long time intervals (20 minutes to 40 minutes) the relevant parameters change significantly and require careful integration (averaging) over time to avoid misleading conclusions. Conclusions of the FU method are only suited to operationally oriented departments as technical engineering departments do not obtain the diagnostic information potentially available from SR trends.

As an illustration of the value of careful integration the following special application of the FU method is shown.
This consists in monitoring data over integrated segments between two beacons (i and j) separated by a known distance (in excess of 200 m). In addition, wind direction / speed and longitudinal component are taken at 5-minutes intervals to compute an equivalent longitudinal component.

$$(W/V)_{\text{mean longitudinal}} = \frac{1}{\Delta T} \int_{ti}^{tj} (W/V)_{\text{longitudinal}} \, dt \text{ (approximated numerically)}$$

$$(XA)_{\text{mean drift}} = \frac{1}{\Delta T} \int_{ti}^{tj} (XA) \text{ drift } dt \text{ (approximated numerically)}$$

$\Delta T = tj - ti$ so that $(W/V)_{\text{mean longitudinal}}$ and $(XA)_{\text{mean drift}}$

For any phase considered, these are calculated in parallel. Mean values for TAS and Mach are similarly computed.

Equivalent still air distances are calculated by adding longitudinal air distance (adding absolute value with headwind, subtracting absolute value with tailwind) to the known ground distance. This can be derived from Jeppesen charts or from the INS or IRS. The latter offers the advantage that route short-cuts can be taken into account.

Fuel consumption is determined by subtracting fuel used indications at time over station (from switchover on FMS and RMI bearings). Time between stations ΔT is determined from a personal stopwatch chronometer.

At high drift angles (> 5 degrees) the wind triangle equations must be taken into account to correctly calculate TAS, GS and longitudinal wind component.

Actual specific range can hence be determined : (+ for headwind component)

$$SR_{\text{observed}} = \frac{\text{Ground distance} + \left| (W/V \right|_{\text{longitudinal}} \times \frac{\Delta T}{60}}{FU_{\text{station j}} - FU_{\text{station i}}}$$

Theoretical specific range data is derived from the IFP using the average longitudinal component experienced.

$$SR_{\text{theroretical}} = \frac{TAS \times \dfrac{\Delta T}{60}}{\left(\dfrac{FU_{\text{station } j} - FU_{\text{station } i}}{\times \Delta T_{\text{theoretical } i \longrightarrow j}}\right)^{*} \times \Delta T}$$

(* theoretical fuel flow at conditions)

Specific range deviations based on the fuel used method can then be determined and represent extended time-averaged results.

$$\Delta SR = \frac{SR_{\text{observed}} - SR_{\text{theoretical}}}{SR_{\text{theoretical}}}$$

This "improved" fuel burn method is operationally attractive but can only be accomplished if the conditions and procedures specified above are strictly and precisely adhered to. This makes this improved version of the FU method cumbersom to apply, although it is easy to integrate into normal aircraft operating procedures.

2.2.2 Measurement procedures and precautions

Figure 6 shows a sample recording form for handwritten observations.

Prior to take-off

- Calculate fuel on board at MES by taking remaining fuel + truck uplift (measured at truck) accounting for actual fuel density
- Determine ZFW and take-off CG
- Note APU running time since MES
- Compute APU fuel consumption to amend FU.

AMP WT AT MES :
APU RUNNING TIME AFTER MES :
AIR CONDITIONING:BLEEDS : E or N

TCC : ON
OFF

ATS : ON
OFF
AUTOPILOT :
C.G. (EST) :

DRIFT :

RUDDER : NR/NL
HOR. STAB :
ZCW or WLV ϕ

DATE :
FLIGHT :
SECTOR :
AIRCRAFT :

UTC	ΣFQI FU1/FU2	HDG W/V TRACK/COURSE	ALT ADC1 and/or ADC2	V_C/M ADC1 and/or ADC2	$SAT_{(TAT)}$ ADC1 and/or ADC2	TAS/V_G/kt ADC1 and/orADC2	N_{11} /N_{12}	FF_1 / FF_2

Figure 6

In flight

- Verify aircraft to be flying level in cruise for at least 30 minutes
- Perform fuel balancing if tank balance exists
- Establish nominal aircraft configuration for the cruise segment where measurements will be taken, i.e. :

- Autothrottle :	ON (or OFF if conditions stable to assess its impact)
- Autopilot :	As required e.g. ALT HLD / HDG SEL or ALT HLD / NAV or PROF / NAV
- Air conditioning :	A310 / A300-600 : N or E A320 : N
- Anti-icing :	OFF
- Trimming :	ZCW or WLV on A310 / A300-600

- allow some parameter variation but not beyond the following limits :

Δ Zp < 50 feet/30 minutes
Δ SAT < 5°C /30 minutes
Δ GS < 10 kts /30 minutes
Δ TAS < 10 kts /30 minutes

- Record data for at least 20 minutes, if conditions permit, from start of period every 5 minutes until the end, using adjacent fuel-used recording form shown in Figure 6 :

- UTC, latitude or station
- CG
- FU_1 / FU_2
- Total fuel on board (FQI)
- Altitude (Zp) - (channel 1 and 2)
- Mach - (channel 1 and 2)
- SAT / TAT
- Track / course
- Wind speed / direction
- Heading and drift
- TAS / VG
- N_{11} / N_{12} (EPR_1 / EPR_2)
- FF_1 / FF_2

- Note also latitude or station approaching, drift, heading, wind velocity / direction, track / course for calculation of effects mentioned in section 3
- Do not forget to consult weather charts (forecasts and actuals) to confirm pressure patterns
- Do not omit to mention TCCS / ARCCS on or off
- Do not omit to note tail number, date, flight sector for referencing

2.2.3 Data analysis procedure

Based on the flight data over the recorded time span, the following parameters will be calculated :

- **Timespan (Δ T) = UTC$_{Stop}$ - UTC$_{Start}$**
- **Gross weight at start**
- **Average altitude (Zp)**
- **Average Mach number (M)**
- **Average TAT/SAT**
- **Fuel used = (fuel used at end - fuel used at start) or (FQI start - FQI end)**
- **Aircraft CG (based on take-off CG and fuel burn schedule).**

The IFP is then used to compute the predicted fuel used for the aircraft flying at the average recorded flight conditions, over a timespan equal to Δt and starting at a weight equal to GW start. The ratio of measured and predicted fuel used will provide the level of performance relative to the published model. The following schematic shows the procedure flow :

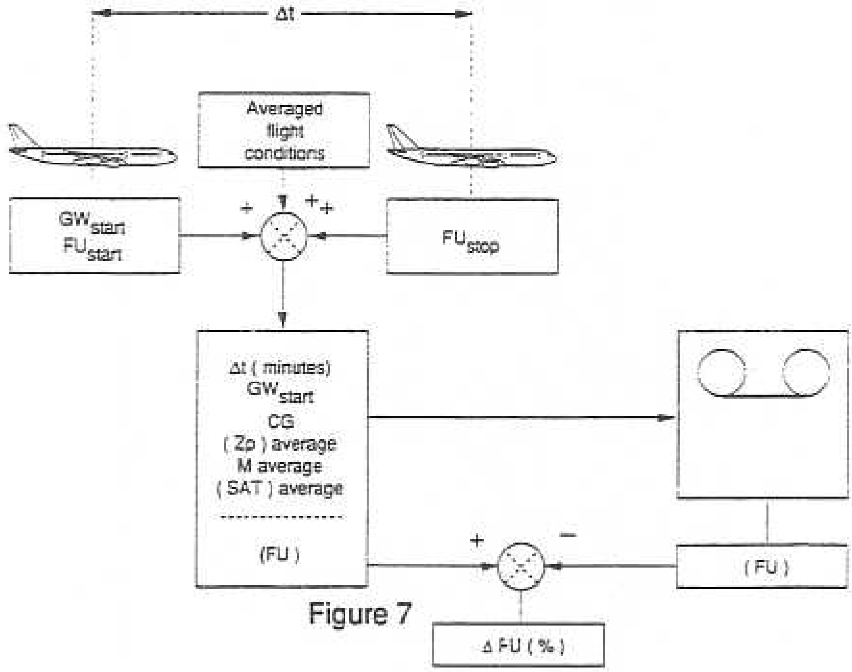


Figure 7

Notes

1) Selection of several 20-minutes samples from the recorded data allows a mean value to be obtained and measurement scatter to be evaluated, which is indicative of flight stability.

2) The "improved" FU method (whose principle is explained in paragraph 2.2.1) gives refined results and allows very precise measurements.

Example

The following example presents an equivalent specific range evaluation with a calculation of observed SR and of theoretical specific range at the Mach numbers of the two ADCs. The corresponding IFP printout is shown in Figure 8 and also exemplifies the FU method.

1) Observed SR calculation :

Δ t = 48 sec 51 m 28/100 ≈ 48.86 minutes
Δ Sg = 388 Nm from Jepessen map
Tailwind = 4.3/hr rom ND/IRS's
ΔSw = - 3.5 Nm (tailwind distance over Δ t)
ΔSa_{obs} = Δ Sg + Δ SW = 384.5 Nm true air distance
Δ FU = 4110 kg i.e. observed fuel consumption on ΔSg ly,
$SR_{observed}$ = 0.935523 (integrated)

2) Calculation of Theoretical Specific Range AT M1

TAS = 475.1 kts at M1 = 0.802 (ADC1)
ΔSa_{th_1} = 386.89 Nm] by interpolation from IFP output.
ΔFU_{th_1} = 3942.33 kg
SR_{th_1} = 0.0981373 (integrated)

$$\Delta SR_1 = \frac{0.0935523 - 00981373}{0.0981373} = 0.04672$$

3) Calculation of Theoretical Specific Range AT M2

TAS = 476.8 kts at M2 = 0.805 (ADC2)
ΔSa_{th} = 388.27 Nm
ΔFU_{th} = 3972.99 kg
SR_{th} = 0.0977274 (integrated)

$$\Delta SR_1 = \frac{0.0935523 - 0.0977274}{0.0977274} = 0.04272$$

4). Specific Range Deviation Calculation

$$\Delta SR = \frac{\Delta SR_1 + \Delta SR_2}{2} = 4.47\ \%$$

2.3 Trip Fuel Burn-off Analysis

This method compounds genuine performance (engine / airframe, instrument accuracy) with apparent performance deviations caused by differences between the actual flight profile (and conditions) and the IFP - predicted fight profile (and conditions) such as :

- wind and SAT profile predictions,
- flight profile (Climb profile, Top of Climb, Cruise Mach, Step Climbs, Top of Descent, Descent profile, Holding) predictions

AIRBUS IFP-V02A P JUNE 1989
A310-304-01 CF6-80C2A2

CLEAN CONFIGURATION

C G POSITION : 36.9 %

AVERAGE ENGINE - FLHV : 18570.BTU/LB

WITHOUT ANTI-ICING ECONOMIC AIR CONDITIONNING

ALTITUDE : 35018.FT ISA + 12.3 DG.C WIND : 4.3 KT

CONVERSION: — for HETON

CRUISE AT .802 MACH NUMBER

OPTIMAL WEIGHT FOR FLIGHT LEVEL IS 129665. KG
THRUST LIMITED WEIGHT EXCEEDS STRUCTURAL LIMIT
BUFFET LIMITED WEIGHT EXCEEDS STRUCTURAL LIMIT

WGHT (KG)	MACH ( )	CAS (KT)	TAS (KT)	TIME (MN)	FUEL (KG)	DIST (NM)	SR (NMKG)	WFE (KG/H)	N1 (%)	EGT (DG.C)	CL ( )	CD ( )	ALPH (DEG.)	FN (DAN)	PCFN (%)
	.802	272.6	475.1	.00	0.	.0	.09732	4926.	94.840	687.	.57290	.03338	2.24	7869.	80.8
137000.	.802	272.6	475.1	16.37	1336.	130.8	.09846	4869.	94.547	684.	.56742	.03296	2.20	7769.	79.8
136000.	.802	272.6	475.1	28.75	2336.	229.7	.09932	4826.	94.331	681.	.56331	.03265	2.17	7695.	79.0
135000.	.802	272.6	475.1	41.23	3336.	329.4	.10019	4785.	94.116	679.	.55921	.03234	2.14	7621.	78.2
134226.	.802	272.6	475.1	50.97	4110.	407.2	.10081	4755.	93.965	678.	.55603	.03212	2.12	7569.	77.7

AIRBUS IFP-V02A P JUNE 1989
A310-304-01 CF6-80C2A2

CLEAN CONFIGURATION

C G POSITION : 36.9 %

AVERAGE ENGINE - FLHV : 18570.BTU/LB

WITHOUT ANTI-ICING ECONOMIC AIR CONDITIONNING

ALTITUDE : 35018.FT ISA + 12.3 DG.C WIND : 4.3 KT

CRUISE AT .805 MACH NUMBER

OPTIMAL WEIGHT FOR FLIGHT LEVEL IS 130659. KG
THRUST LIMITED WEIGHT EXCEEDS STRUCTURAL LIMIT
BUFFET LIMITED WEIGHT EXCEEDS STRUCTURAL LIMIT

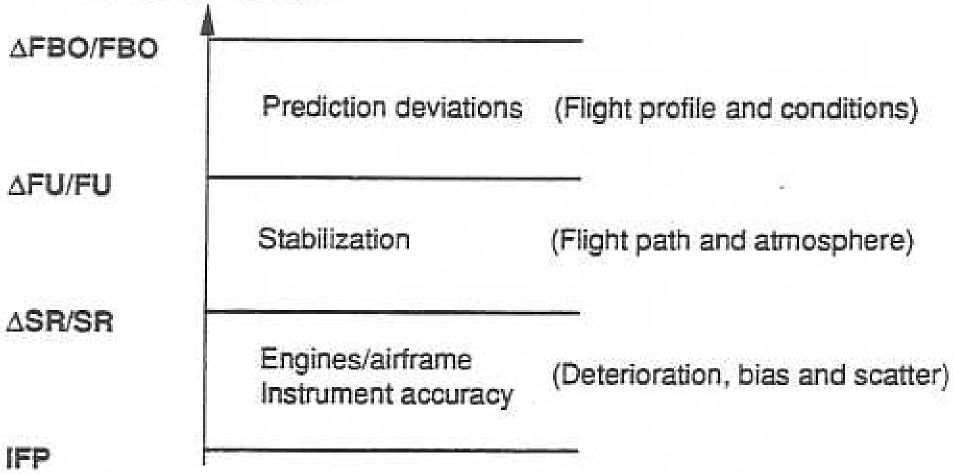
WGHT (KG)	MACH ( )	CAS (KT)	TAS (KT)	TIME (MN)	FUEL (KG)	DIST (NM)	SR (NMKG)	WFE (KG/H)	N1 (%)	EGT (DG.C)	CL ( )	CD ( )	ALPH (DEG.)	FN (DAN)	PCFN (%)
138336.	.805	273.7	476.8	.00	0.	.0	.09684	4968.	95.016	689.	.56869	.03339	2.19	7927.	81.5
137000.	.805	273.7	476.8	16.23	1336.	130.2	.09805	4907.	94.703	686.	.56325	.03293	2.15	7820.	80.3
136000.	.805	273.7	476.8	28.52	2336.	228.7	.09897	4861.	94.469	683.	.55918	.03260	2.12	7740.	79.5
135000.	.805	273.7	476.8	40.91	3336.	328.1	.09978	4822.	94.267	681.	.55511	.03231	2.09	7670.	78.8
134226.	.805	273.7	476.8	50.57	4110.	405.5	.10037	4794.	94.122	679.	.55195	.03210	2.07	7621.	78.3

Figure 8

- Fuel burn-off predictions (model, performance factor, LHV)
- Operational factors (e.g. center of gravity position, air conditionning mode, aircraft weight, aircraft trimming)
- Environmental factors (e.g. Coriolis-effect, Local gravity, centrifugal effect, isobaric slopes caused by pressure and temperature gradients)

As in the FU-method all flight parameters are averaged over time segments to allow a numeric approximation per flight phase prior to input into the flight plan recalculation.

The graph below illustrates how the $\Delta SR / SR$, $\Delta FU / FU$ and $\Delta FBO / FBO$ relate to each other and relative to the IFP baseline.



2.4 Conclusion

All the above methods naturally have relative advantages and disadvantages which airlines have to balance as they see fit.

	Advantages	Disadvantages	Comments
Specific range method	- Potential splitting of engine and airframe - Easy processing	- Noise, sensitive - Stability critical	- Not adapted for factoring on short/ medium-haul
Fuel-used method	- Easy data gathering - Noise elimination - ATS remaining in use	- No bias elimination - Tedious processing	- Adapted for flight planning - Operational conditions
Trip fuel burn-off analysis	- Noise elimination - ATS remaining in use	- More crew attention required - Tedious data gathering and processing	- Adapted fuel factoring on short-haul

Measurement bias / scatter

Bias/Scatter		Effect	APM UNI 10 Inclusion	Measurement Precaution	Walkaround & flight lookout	Correction Factor	ECM
[X]		Center of gravity	▨				
[X]		Air conditioning	▨				
[X]		Aircraft weight		☐			
[X]		Aircraft trimming		▨			
[X]		Aircraft surfaces (rigging)			▨		
[X]		Bleed / pressurization	▨	▨			
	[X]	Coriolis - effect	☐				
	[X]	Centrifugal effect	☐				
	[X]	Variation of local gravity	☐				
	[X]	Isob. slope (press. grad)				☐	
	[X]	Isob. slope (temp. grad)				▨	
[X]	[X]	LHV	☐				
[X]	[X]	Data acquisition / Transmission		☐			
[X]	[X]	Instrument accuracy (f-f meters)		☐			
[X]	[X]	Engine effects (HPT ACC, ARCCS / TCCS deterioration					☐

Potential ΔSR - effect ☐> 0.8% 0.3% > ▨ < 0.8 ☐< 0.3%

Figure 9

However for each of these it is necessary to take into account several correction factors or measurement precautions to reduce the bias / scatter band. These considerations are reviewed in section 3 below.

Also, the trend should be observed over a sufficiently long period as explained in paragraph 4. Furthermore, in the operational context of airline auditing one should refrain from absolute conclusions even if maximum precautions are taken to measure some parameters (absence of instrument calibrations, e.g. trailing cone).

3. Measurement factors, corrections and precautions

3.1 Overview

Figure 9 reviews the principal effects relative to measurement bias / scatter, which Airbus Industrie now routinely includes as corrections to audit measurement points. Assumptions and formulae for all these factors were expressed at length in the proceedings of the Performance and Operations Conference held in Bangkok, February 17th - 20th 1986. Since then, refinements with regard to correcting for :

- Coriolis effect
- earth centrifugal effect
- variation of local gravity
- LHV

are now also available in the performance monitoring program version APM UNI 10. The purpose of this section is to cover several aspects on those bias / scatter effects which have appeared since then.

They provide useful feedback experience illustrating the numerous precautions that need to be taken to relate actual aircraft performance back to its factual baseline. Figure 10 illustrates a typical example of an airline claim : the vertical stack-up consists of identifying the principal factors (operational (BIAS), environmental (SCATTER), technical (BIAS and SCATTER)) and deterioration effects (engine, airframe, instruments) causing overall aircraft performance to deviate from the nominal baseline.

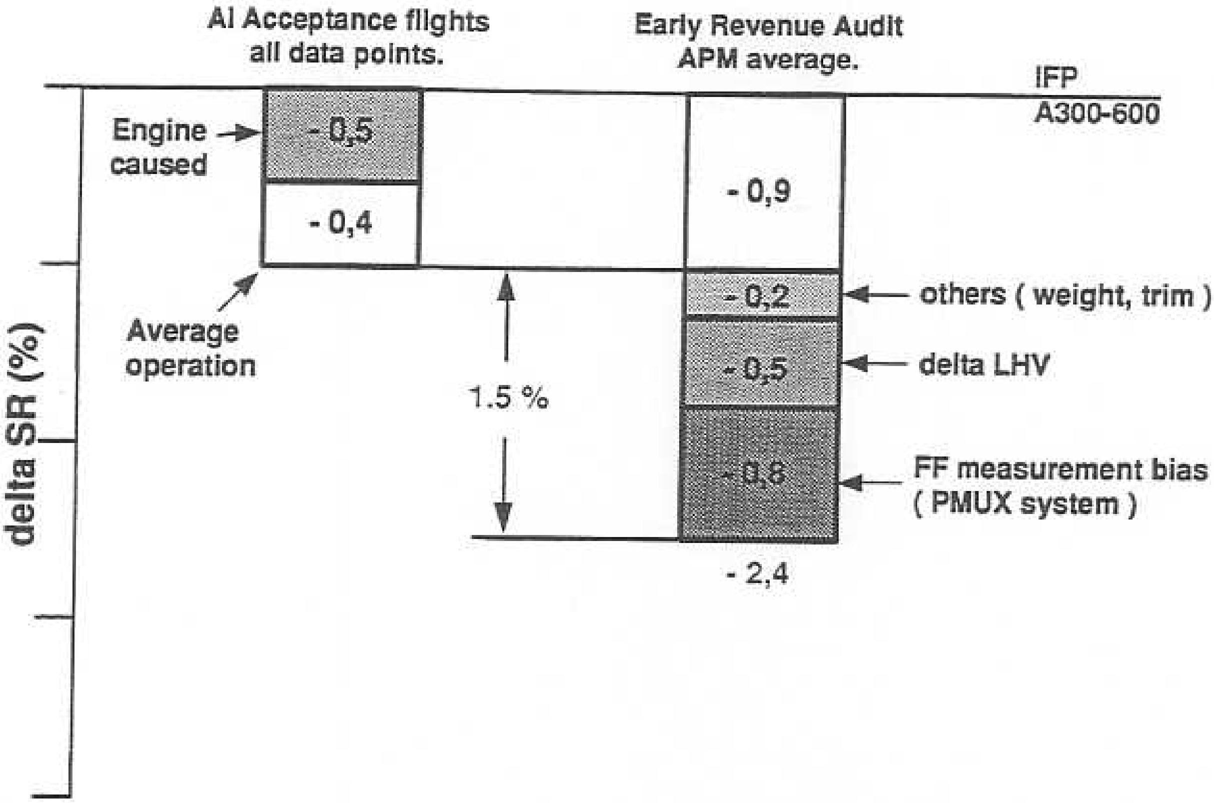


Figure 10 : A300-600 audit stackup example

3.2 Operational factors

3.2.1 Aircraft weight (BIAS)

In 1986 Airbus Industrie already reported the marked tendency of increasing passenger weights, mainly because of higher proportions of carry-on baggage and duty-free articles. On one of our audits we even went as far as weighing four aircraft on a multi-platform system which indicated an average difference of 430 kg between actual and loadsheet (max of 1 ton).

IATA APTF STD-PASSENGER-WEIGHT SURVEY (May 1991)

Airline	Domestic				International				Baggage		Remarks
	Male	Female	Adult	Child	Male	Female	Adult	Child	carry on	checked	
ACA	85	64	77(82)	36	85	64	77(82)	36			( ) Businesstravel route ← On Weight Crit. Flights
SAS	80	65	77 (80/20%)	35	80	65	77 (80/20%)	35			Expect that JAA will require 84 kg
UAL	82.8	69.2	78.3	36.3		Europa Pacific Asia	78.0 75.5 69.2	5.7 7.7 ★			★ 7.7 for Europe only (beer steins?)
UTA	78	68	75 (70/30%)	35	78	68	75 (70/30%)	35	3		for NOU-TYO 65 kg for av. pax weight
SWR			78	31			78	31			Sepcial weighing for nonstandard groups
AFR	78	68	75 (70/30%)	35	78	68	75 (70/30%)	35			Lower weights on Japan flights for asiatic people (65 kg)
AAL			So 81.5 Wi 83.9			Europa Asia	So 78.0 Wi 80.3 So 73.9 Wi 76.2		Dom. 8.1 Eur. 7.7 Asia 10.0		Domestic Weights acc. to FAA draft. Very detailed splitting!
AZA	80	63	75.0 (70/30%)	35	80	63	75.0 (70/30%)	35			Split values for male/female from recent survey Jun/Jul 91
BAW	78	68	77 (90/10%)	43	78	68	77 (90/10%)	43	3		new survey in progress
DLH			78 84				78 81		5 5		← present ← latest survey, subject to authority approval
FAA			81.6 83.9	40.8 40.8			81.6 83.9	40.8 40.8	4.5 4.5		← Summer ← Winter Draft
JAA	88	70	84 (80/20%)	35	88	70	84	35			Draft
NWA			74.8 77.1	38.5 38.5			74.8 77.1	38.5 38.5	2.3 2.3		← Summer ← Winter
SAA	91	72	85.7 (72/28%)	35	91	72	83.8 (62/38%)	35			Survey Jul 90
KLM			77	35			77	35		14.5	
ANA			68	31.7			72.6	36.8			Special handling of special weight groups (Sumo-fighters!)
VRG			75	35			75	35	5		Trend to 85 kg
CDN	83.9	62.6	71.1	34.0	83.9	62.6	71.1	34.0	2.3 2.3		← Latest survey (??) ← On Range Crit. Flights .
RJA			75	35			75	35			
JAL			65.7	31.7			72.6	36.6		★	★ Special handling see JAL-Answer

Figure 11

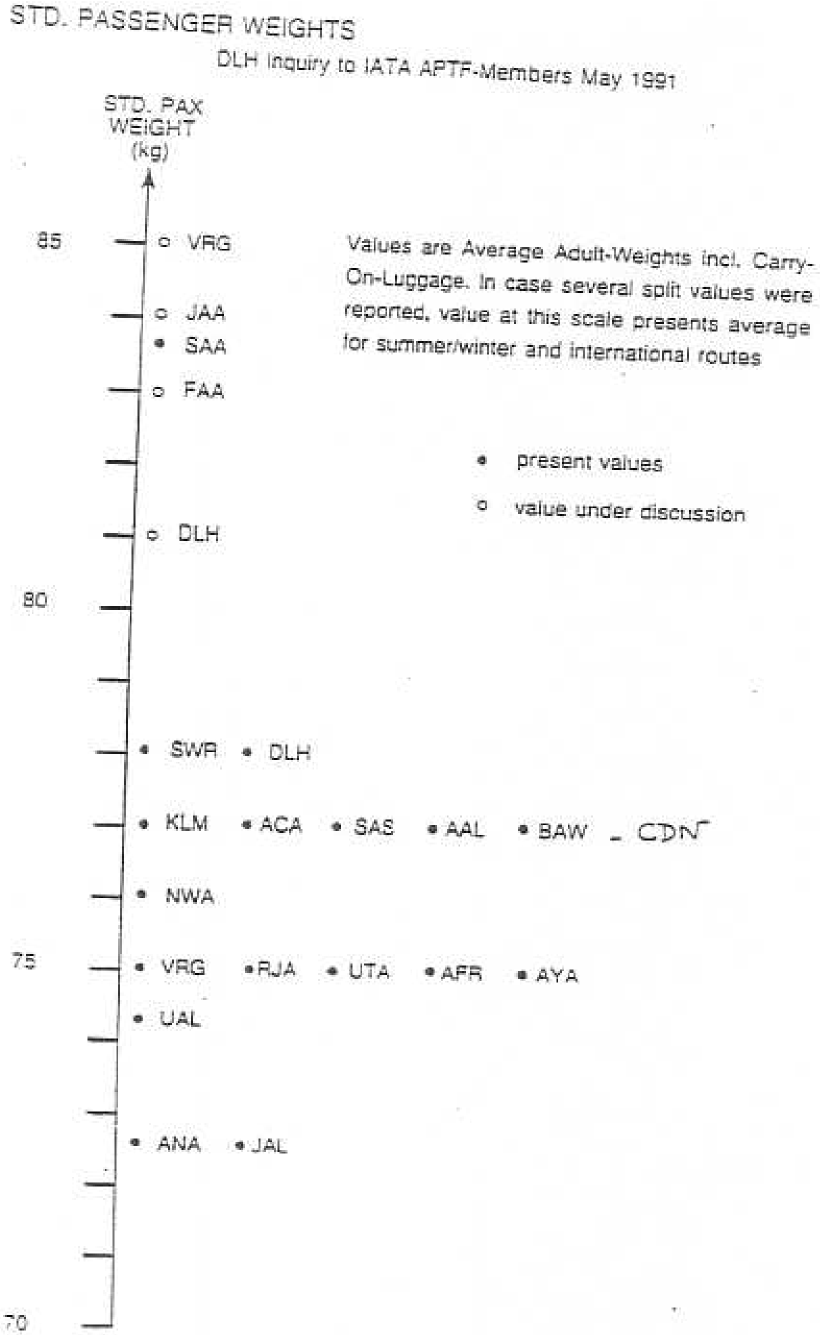

STD. PASSENGER WEIGHTS
DLH Inquiry to IATA APTF-Members May 1991
STD. PAX WEIGHT (kg)
85
80
75
70
o VRG
o JAA
• SAA
o FAA
o DLH
• SWR • DLH
• KLM • ACA • SAS • AAL • BAW _ CDN
• NWA
• VRG •RJA • UTA • AFR • AYA
• UAL
• ANA • JAL
Values are Average Adult-Weights incl. Carry-On-Luggage. In case several split values were reported, value at this scale presents average for summer/winter and international routes
• present values
o value under discussion

Figure 12

The enquiry conducted by the CAA during the 1981 / 82 shoulder season has repeatedly been utilized by Airbus to increment airline passenger weights (male, female, child, infant from CAA paper 83003). Since then, numerous airlines have organized their own surveys as exemplified by Figure 11 and summarized Figure 12 in an IATA inquiry carried out by Lufthansa in May 1991.

In Europe, the JAA has produced a draft JAR OPS (1.4) on passenger and baggage standard weights. This regulation proposes that, for the purpose of calculating the mass of an aircraft, the total masses of passengers, their hand baggage and checked baggage entered on the loadsheet shall be computed using :

- either actual mass values to be weighed case-by-case
  (if the flight should be identified as carrying excessive weights)

- or standard mass values such as :

a) passengers including hand baggage :

	ADULT
All flights except	84 kg / 185 lb
Holiday charters	76 kg / 168 lb
Children (2-12 years)	35 kg / 77 lb

b) checked baggage (if not weighed)

All flights except domestic and Intercontinental Flights	13 kg / 25 lb
Domestic flights	11 kg / 24 lb
Intercontinental flights	15 kg / 33 lb

Infants below 2 years of age would not be counted if carried by adults on passenger seats, would be regarded as children when occupying separate passenger seats.

A suitable statistical method is given in ACJ OPS 1-4 for verifying or updating the standard mass values for passengers and baggage, should an airline choose to prove other weights by looking into its own operations. This would involve taking random samples, the selection of which should be representative of the passenger volume (weighing at least 2000 pax), the type of operation and the frequency of flights on various routes. Significant variations in the masses of passengers and their hand baggage must clearly be accounted for. Anyway a review of these weights will have to be performed every five years, and the loadsheet should always contain references to the weighing method adopted.

The figures given in the above have been drawn mainly from Northern and Central Europe, so the JAA Standard Weights Study Group was still not able to base its figures on an all-European mean.

Initially, the following standard mass values for males and females including hand baggage had been agreed upon :

	Male	Female
Scheduled, medium / long-haul	86 kg / 190 lb	69 kg / 152 lb
Scheduled, European short-haul	89 kg / 196 lb	71 kg / 157 lb
Non-scheduled	84 kg / 185 lb	69 kg / 152 lb

The available data did not show large differences between summer and winter weights. No difference was made therefore. Short-haul flights are predominantly used by businessmen travelling without checked baggage. On long-haul flights, there are obviously less "hand baggage only" passengers. The non-scheduled "summer holiday" passenger is generally lighter carries less hand baggage. In practice, the male / female ratio may show large variations, there are many flights with significantly less than 20% females, and there are not a lot of high quality surveys available, therefore a conservative ratio of 80 / 20 was retained for determining the present all-adult standard mass value of 185 lb on scheduled flights. For non-scheduled flights (168 lb) a 50 / 50 ratio was chosen. Any variation from these ratios on specific routes or flights would have to be substantiated by a survey weighing plan.

In the USA, the FAA has issued an Advisory Circular to provide methods and procedures for developing weight and balance control . This also involves initial and periodic re-weighing of aircraft (every 3 years) to determine average empty and actual operating weight and CG position for a fleet group of the same model and configuration. In the past, the following standard average weights had been adopted :

	Adult	Child (2-12 yrs)
Summer (1/5 thru 31/10)	73 kg / 160 lb	36 kg / 80 lb
Winter (1/11 thru 30/4)	75 kg / 165 lb	36 kg / 80 lb
Carry-on baggage allowance	4.5 kg / 10 lb	4.5 kg / 10 lb

AC 120 - 27 B features a 10 lb increase in these weights :

a) Standard average passenger weight

	Adult	Child (2-12 yrs)
Summer (1/5 thru 31/10)	77 kg / 170 lb	36 kg / 80 lb
Winter (1/11 thru 30/4)	80 kg / 175 lb	36 kg / 80 lb
Carry-on baggage allowance	4.5 kg / 10 lb	4.5 kg / 10 lb

b) Non standard average passenger weight

- actual weighing for non-standard groups (athletic squads, etc)
- military groups
  - Non-combat-equipped : 88 kg / 195 lb
    (incl. 20 lb of hand-carried baggage)
  - Combat-equipped : 102 kg / 225 lb
    (incl. 20 lb of hand-carried baggage
    + 10 lb of hand-carried weapons)

c) Crew weight

	Male	Female
- Flight crew member	68 kg / 150 lb	59 kg / 130 lb
- Cabin attendant	77 kg / 170 lb	59 kg / 130 lb

d) Baggage

	Checked	Hand baggage allowance *
- FAR 121 / domestic	10.5 kg / 23.5 lb	4.5 kg / 10 lb
- International / non-scheduled	12 kg / 26.6 lb	4.5 kg / 10 lb

* whether or not carried by the passenger

Following comments by the US operators, the AC 120-27 B (essentially featuring a 10 lb increase in the original passenger weights) has been suspended. A comprehensive review is currently underway under the auspices of the ATA. Participating, are the FAA, Delta Airlines, American Airlines, ALPA, APA, IAM, Boeing, McDonnell Douglas and a group of smaller airlines (regionals / commuters). It was understood in mid-January that this working group would revise the JAR OPS (1.4) by adopting an adult mass value of 180 lb (82 kg) based on a 60 / 40 male / female ratio and doing away with winter / summer / holiday destination distinctions. Checked baggage allowances would be 23.5 lb / 26.5 lb respectively for domestic / international passengers, possibly to be revised towards 25 lb / 30 lb.

AVERAGE PASSENGER WEIGHT

DATA SOURCE	AAL DOMESTIC LB.	AAL EUROPEAN LB.	AAL TOKYO LB.	AAL CTR & SO. AMERICA LB.
AVG MALE	188.45	181.41	170.1	182.77
AVG FEMALE	143.4	141.95	122.2	140.38
* ACTUAL % PASSENGERS MALE/FEMALE	AVERAGE PASSENGER WEIGHT (LB.)			
50 / 50	165.79	161.68	146.15	161.67
55 / 45	168.06	163.65	148.54	163.08
60 / 40	170.32 171.18*	165.62 165.70*	150.94	165.93
65 / 35	172.59	167.59	153.33	165.06 166.75*
70 / 30	174.85	172.57	155.73 156.87*	171.09
*ACTUAL % PASSENGERS MALE/FEMALE/ CHILDREN				
59.95 / 36.88 / 3.12	168.31			
58.6 / 38.5 / 2.9		163.27		
69.2 / 26.4 / 4.3			1 ·97	
58.1 / 35.2 / 6.7				161.23

* The actual male/female adult survey results.

Figure 13

Similar to JAA, airlines will have to adopt standard weights unless they request different values which would have to be proven by a survey at the risk of ending up with higher statistics. Regional exceptions (e.g. USA - Asia traffic as exemplified for American on Figure 11) would be allowed when substantiated by means of an accepted methodology (to be put in Appendix as for the JAA). No time restrictions are to be imposed for individual operator reviews (as for JAA : 3 years), periodic revisions being preferred.

The impact of these regulatory stipulations on TOW, TOD, payload (restrictions) and cruise mileage is evident. A harmonization between FAA and JAA is desirable as it would eventually prompt all airlines (including conservative ones) to undergo the same penalties (cf. Amendment 42) with minimal competitive detriment. Safety implications are also involved, as unrealistic weight figures may certainly put some aircraft at risk during the take-off phase.

As will be seen in the figure concerning trending (cf. paragraph 4.2), adding extra allowances for carry-on baggage (in agreement with the airline) from certain departure points (ex-holiday, ex-USA) often results in decreased DN_1 mean values and decreased DN_1 standard deviations (especially if the audit comprised a round-trip on the same aircraft ; outbound and inbound flights should normally not show any changes in DN_{1S} values ; no change in N_1 / thrust relationship, no change in aerodynamics).

3.2.2 Airframe maintenance and aerodynamic deterioration (BIAS)

In order to complement performance data, whenever possible the audited aircraft is observed on ground (to be confirmed with photographs) and in flight for any surface misalignment or other aerodynamic discrepancy such as :

- door misrigging
- missing or damaged door seal sections
- control surface misrigging (see Figure 13)
- missing or damaged seal sections on movable surfaces
- skin dents and surface roughness
- skin joint filling compound missing or damaged.

Control surface mis-rigging

Control surface	Estimated percentage of increased drag for surface misrigging — Height 5 mm	10 mm	15 mm	Corrective action (inspection + rigging)	AMM reference	Man hours	Check interval
SLAT	0.09%	0.2%	0.3%	Adjustment of slats	27-80-00	2 per slat	Visual inspection A-check
				Folding nose adjustment	27-81-33 p. 403		
				Fairing plate adjustment	27-81-34 p. 402 27-81-58 p. 903, 904, 905		
				Krueger flap adjustment	27-87-11 p. 406, 407 (A300, A300/600) 27-87-00 p. 501, 505 (A310)		
				Notch flap adjustment	27-87-13 p. 405 (A300, A300/600)		
				Movable vane adjustment	27-87-12 p. 405 (A300, A300/600)		
FLAP	0.04%	0.07%	0.1%	Adjustment of flaps	27-50-00	3 per flap	Rigging : C-check
				Movable fairings flap track adjustment	27-50-21 p. 406, 408		
				Fairings operating rod adjustment	27-50-22 p. 404		
Spoiler	0.1%	0.23%	0.36%	Adjustment of spoilers	27-61-00 p. 501	2 per spoiler	
Aileron	0.04%	0.07%	0.1%	Adjustment of all speed ailerons	27.11.00 p. 501	4 per aileron	
Rudder	0.05%	0.09%	0.12%	Adjustment of rudder	27-21-00 p. 501	3	
Elevator				Adjustment of elevators	27-31-00 p. 501		
THS				THS adjustment	57-10-11		

. Middle slat section :
LH (15 mm forward step) : $\Delta C_d = 0.46\ d_c$
RH (10 mm forward step) : $\Delta C_d = 0.33\ d_c$

. Aft facing step, entire middle slat section :
LH (1 mm) : $\Delta C_d = 1.42\ d_c$
RH (0.5 mm) : $\Delta C_d = 0.9\ d_c$

. Inner-Mid slat junction aft step both wings :
(5 mm by 50 cm wide) : $\Delta C_d = 2 \times 0.22\ d_c$
or $= 0.44\ d_c$

. All Speed Ailerons : both
(0.5° inboard angle tilt) : $\Delta C_d = 2 \times 0.5\ d_c$
or $= 1.0\ d_c$

. Spoiler Upfloat :
LH (1 with 2 mm step) : $\Delta C_d = 0.18\ d_c$
RH (3 with 5 mm steps) : $\Delta C_d = 1.32\ d_c$

. Nose Radome step :
(2 mm by 1.7 m circumference) :
$\Delta C_d = 0.016\ d_c$

. Inspection hatch behind RH wing :
(20 cm x 20 cm, fwd step 2 mm) : $\Delta C_d = 0.002\ d_c$
aft step 1 mm) : $\Delta C_d = 0.001\ d_c$

. Cargo door dents :
(1.5 cm x 20 cm) : $\Delta C_d = 0.015\ d_c$

. Toilet Service Door :
(3 mm step x 10 cm) : $\Delta C_d = 0.001\ d_c$

. Service Door :
(2 mm step x 10 cm) : $\Delta C_d = 0.001\ d_c$

Estimated extra drag counts : 6.09
Estimated DFF / DSR penalty : 2.0 %

Parasitic Drag Assessment Example

Figure 14

- In flight this would specifically pertain to :

  - slats alignment and seating
  - pylons and pylon- to-wing interfaces
  - engine cowlings
  - spoilers trailing edge seating and seal condition (rubber or brush)
  - flaps, flap tabs and all-speed ailerons trailing edge alignment.

- On ground this would specifically pertain to areas 1 (forward) and 2 (mid)* :

  - static and dynamic pitot condition
  - nose radome misalignment
  - cargo door to fuselage alignment
  - service door condition
  - engine fan blade condition (curling, etc.)
  - surface cleanliness (hydraulic fluid, dirt, paint peeling, etc.)
  - underwing condition
  - wing-body fairing
  - nose and main landing gear door adjustment
  - temporary surface protection remmants.

* area 3 being the aft

Figure 14 shows a fictitious example of a very unclean aircraft. Consultation of the A310 drag assessment handbook would show an estimated amount of 6.09 extra drag counts equating to a specific range deficit of 2.0 %. Appropriate analytical estimates of extra drag and fuel flow consequences and judicious gross weight assumptions can hence be instrumental in explaining APM outputs (DN_1, DFF_1, DFF_2, DSR).

3.2.3 Aircraft trimming and asymmetry diagnosis (BIAS)

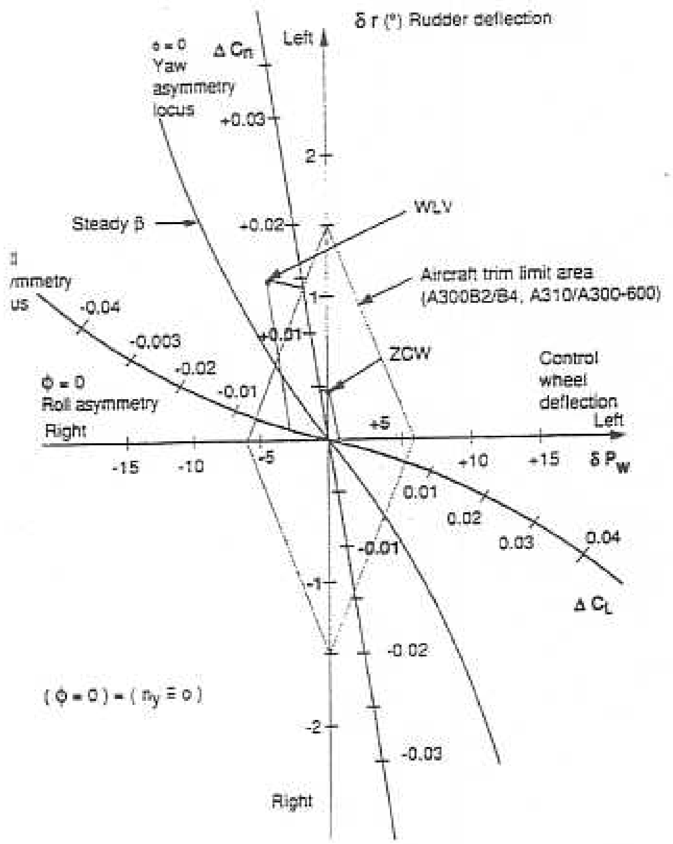
As explained at the Bangkok 1986 AI Operations and Performance Conference, accurate and repetitive trimming allows to identify the origin of small but persistent asymmetries to be identified on A300B2 / B4 and A310 / A300-600 aircraft.

The reasons for these asymmetries can be several :

- general production tolerances, particularly wing tolerances and asymmetry between both wings in dimensions, wing / fuselage local setting, wing twist
- control surfaces rigging tolerances, particularly for rudder, ailerons and spoilers,
- fuel loading asymmetries between both wings, although displayed FQI values are symmetrical
- thrust setting asymmetries between both engines, although displayed N1 / EPR values are symmetrical
- cargo or passenger loading asymmetries

All of these could lead to an aircraft not flying straight in cruise with all lateral / directional control surfaces in perfectly neutral positions.

Recorded zero control wheel and wings-level trim points on the adjacent figure are plotted to represent the level of pure yaw and roll asymmetries in the rudder versus wheel deflection field. The associated DFF / DSR are then readily computed and can also be compared to corresponding APM outputs (ZCW / WLV). The following example illustrates this audit procedure to perform asymmetry diagnosis on A310 aircraft (FCOM 2.02.09)



ZCW - trimming
incl. ΔSR (ZCW)

δr = 0.3 L ϕ = 1.0 L
ΔC_l = 0.002   ΔSR = −0.10%
ΔC_n = 0.004   ΔSR = −0.20%

WLV - trimming
incl. ΔSR (WLV)

δr = 1.1° NL ϕ = 0
δp_w = 1.75 x 4 = 7.0 RWD
ΔC_l = 0.004   ΔSR = −0.25%
ΔC_n = 0.013   ΔSR = −0.55%

Δ[ΔSR(ZCW/WLV)] FROM CALCULATIONS	Δ[ΔSR(ZCW/WLV)] FROM APM RESULTS
-0.50%	-0.55%

Figure 16

A310 Asymmetry diagnosis and trim limits wings level loci for roll and yaw asymmetrics

- ΔFQI L/R ⩽ 0.1 T - AP CMD (alt h/d HD Gel)
- ΔN 11/2 ⩽ 1% - ATS OFF
  Bank angle $\phi \leqslant$ 1.5°

The specific range deterioration of 0.3% (ZCW condition) due to aircraft asymmetry is included in the total DSR discrepancy attributable to aerodynamics shown in Figure 15

As on the earlier A310 model, a flap adjustment procedure for asymmetric flight compensation has also been developed for the A320 to reduce asymmetry drag to a maximum. Aircraft not flying straight then have to be trimmed by rudder trim - AP engaged - the ailerons remaining in neutral position for a bank angle less than 1.5°. A correction factor C_f is thereby computed to determine the flaps rigging to be performed.

$C_f = DN + 0.7\,\phi - 0.25\,(DL_{left} - DL_{right})$

with
- ϕ : bank angle (> 0 if right wing low)
- $DL_{(left)}$, $DL_{(right)}$: aileron deflections (> 0 if trailing edge of aileron down)
- DN : rudder deflection (> 0 if trailing edge of rudder left)

- if $|C_f| < 0.5$ no action required
- if $|C_f| > 1.5$ rigging check of ailerons, rudder and internal flap before repeating the procedure flight or recomputation)
- if $|C_f| > 0.5$ external flap position only correction as follows.

1) external flaps trailing edge movement
$\Delta Z_{mm} = 9 \times C_f$

2) 50 / 50 sharing between the two flaps if possible

3) if $C_f > 0$
- right flap must be moved down
- left flap must be moved up

ex. $C_f = 1.1$ $Z_{mm} = 10$ mm
rigging tolerance $\Delta Z_{mm} = \pm 2$ mm

	Left flap	Right flap
Ideally	up 5 mm	down 5 mm
Other possibilities	up 3 mm up 0	down 7 mm down 10

4) check $C_f| < |0.5$ on subsequent flight.

3.2.4 Bleed and pressurization (BIAS)

Cabin air leakage may result in increased engine bleed extraction (for the same thrust) and aerodynamic flow losses. Difficult to assess acceptance / delivery flights sometimes involve closing all bleed / packs (A310 / A300-600) or both packs (A320) at maximum altitude to monitor cabin climb rate. If this exceeds the nominal rate (2000 f pm on A310 / A300-600, 750 pm on A320) indications are strong that extra leakages exist (door sealings, windows, etc.), easily detectable by leakage noise. Occasionally a ground pressurization test is performed, the aircraft having been sprayed with a leak-detecting soap solution (as specified for example in A320 AMM 05-53-00 pages 501 thru 513).

Selecting anti-ice and measuring cruise performance can also give a useful comparison with anti-ice off. The nominal extra fuel consumption at flight conditions can be calculated from the IFP and compared with the measured difference in fuel consumption / SR with and without anti-ice. For those cases where this measured difference is below the nominal difference, it can be hypothesized that some bleed leaks in the anti-ice ducts may be at the origin of engine fuel flow deviation with anti-ice off (and ensuing loss of fuel efficiency). This test is performed for qualitative purposes only, and alludes to the possibility of leaks without necessarily estimating the extent or amount of actual engine deviation.

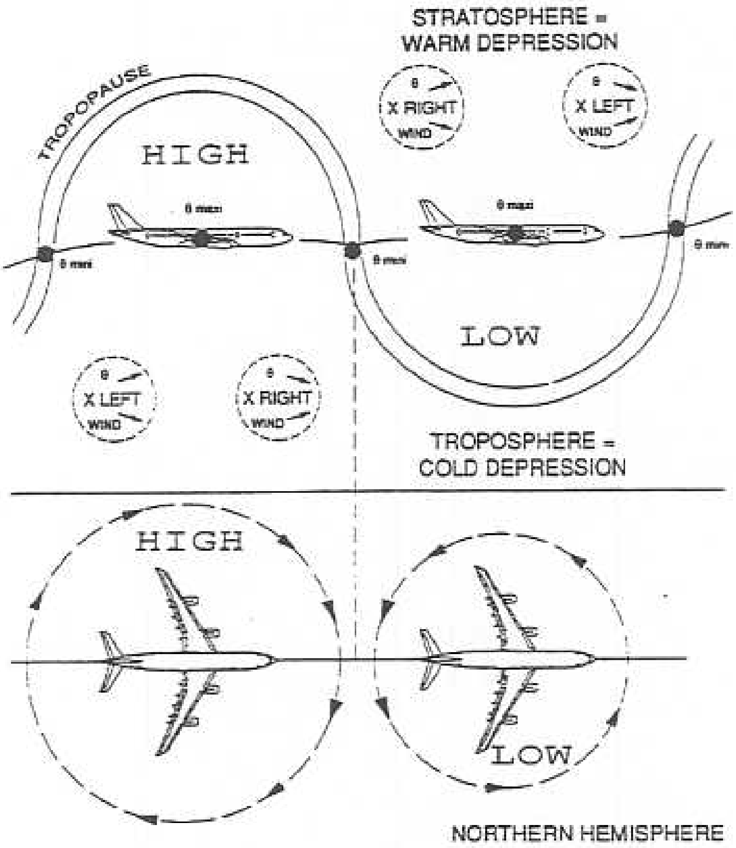


Figure 15

3.3 Environmental Factors

3.3.1 Pressure gradient Isobaric slope (BIAS/SCATTER)

By maintaining constant pressure altitude, an aircraft may actually be climbing or descending as the isobaric pattern changes. In performance flight test, isobars are usually followed to minimize drift angle. In airline revenue service, this is not feasible since airways cut across the isobars.

The isobaric slope can be related to the drift angle as illustrated in Figure 16.

In the Northern Hemisphere :

- **RH drift angle** corresponds with wind from the left,
  → the aircraft is flying towards a low pressure zone : **(downhill)**
  - in the troposphere, $\left\{\begin{array}{l}\text{SAT decreasing}\\ \text{wind increasing}\end{array}\right\}$
  - in the stratosphere, $\left\{\begin{array}{l}\text{SAT increasing}\\ \text{wind decreasing}\end{array}\right\}$

- **LH drift angle** corresponds with wind from the right,
  → the aircraft is flying towards a high pressure zone **(uphill)**
  - in the troposphere, $\left\{\begin{array}{l}\text{SAT increasing}\\ \text{wind decreasing}\end{array}\right\}$
  - in the stratosphere, $\left\{\begin{array}{l}\text{SAT decreasing}\\ \text{wind increasing}\end{array}\right\}$

Wind velocity increases below the tropopause and decreases above the tropopause by approximately 5% per 1000 ft except in jet stream zones. Near the tropopause, the wind velocity is maximum (approx. 2000 ft below).

The opposite phenomena prevail in the Southern Hemisphere.

In order to account for this isobaric slope the aircraft :

- Should be given a **positive compensation when flying uphill**
  (i.e. LH drift angle in Northern Hemisphere/RH drift angle in Southern Hemisphere)

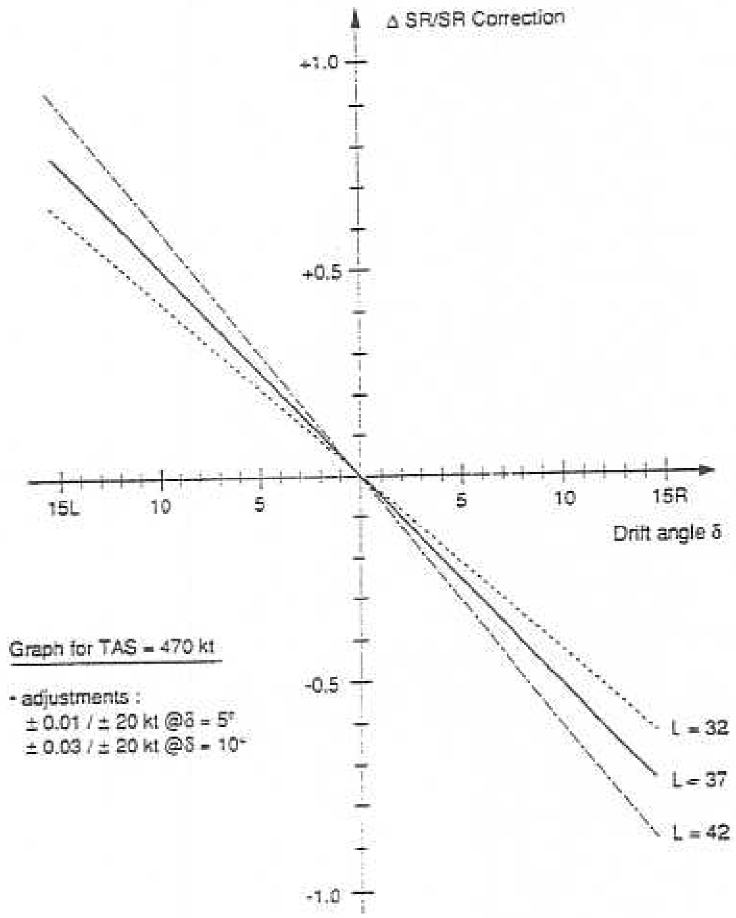
- Should be given a **negative compensation when flying downhill**
  (i.e. RH drift angle in Northern Hemisphere/LH drift angle in Southern Hemisphere)

The formulation to compute the DSR correction was theoretically divulged in a paper given at the 1986 Performance and Operations Conference with a graphic provided in Figure 17.

In practice, drift (track-heading), temperature (SAT) and wind observations (direction/speed) should be compared with air weather maps showing :

- pressure patterns (highs and lows)
- wind barbs (direction/speed/FL)
- tropopause height
- stratospheric lapse rate
- temperature trends around tropopause
- jetstream core locations
- turbulence areas.

In any case the aircraft needs to be stabilized (FPAC, VV) as specified earlier.

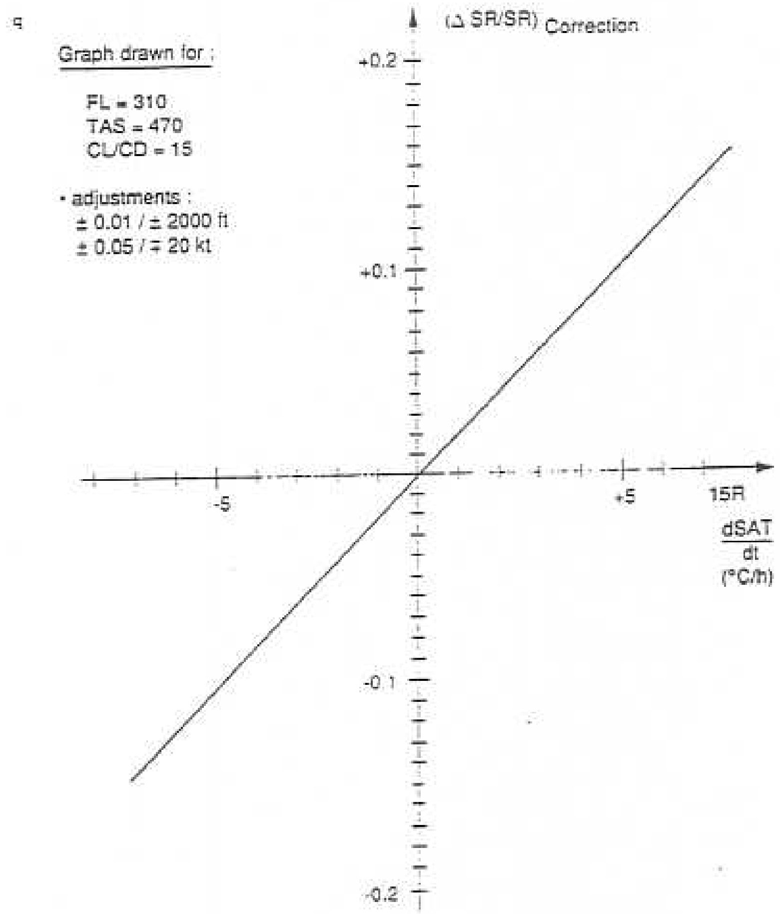


$$(\Delta SR/SR)_{Correction} = -1.107 \times 10^{-2} \times TAS \times \sin L \times \tan \delta$$

Figure 17

In audits, one would refrain from taking stabilized cruise performance readings if the pressure system is changing rapidly or when drift angles are greater or equal to 5 degrees. Very often, a positive ΔT can be observed (~10° C in horizontal flight) when passing through the tropopause from the troposphere to the stratosphere. This temperature increase is even more noticeable when the tropopause slope angle is steep and therefore when the wind velocity is highest at the point where the tropopause is passed through.

The equation in Figure 17 is valid only for geostrophic winds ; less-than ideal conditions like topographic effects (mountain waves) or strong curvature of the isobars > 5° drift would lead to erroneous results.



$$(\Delta SR/SR)_{Correction} = 0.0094 \times (0.25FL - 11.5) \times \frac{C_L}{C_D} \times \frac{1}{TAS} \times dSAT$$

Figure 18

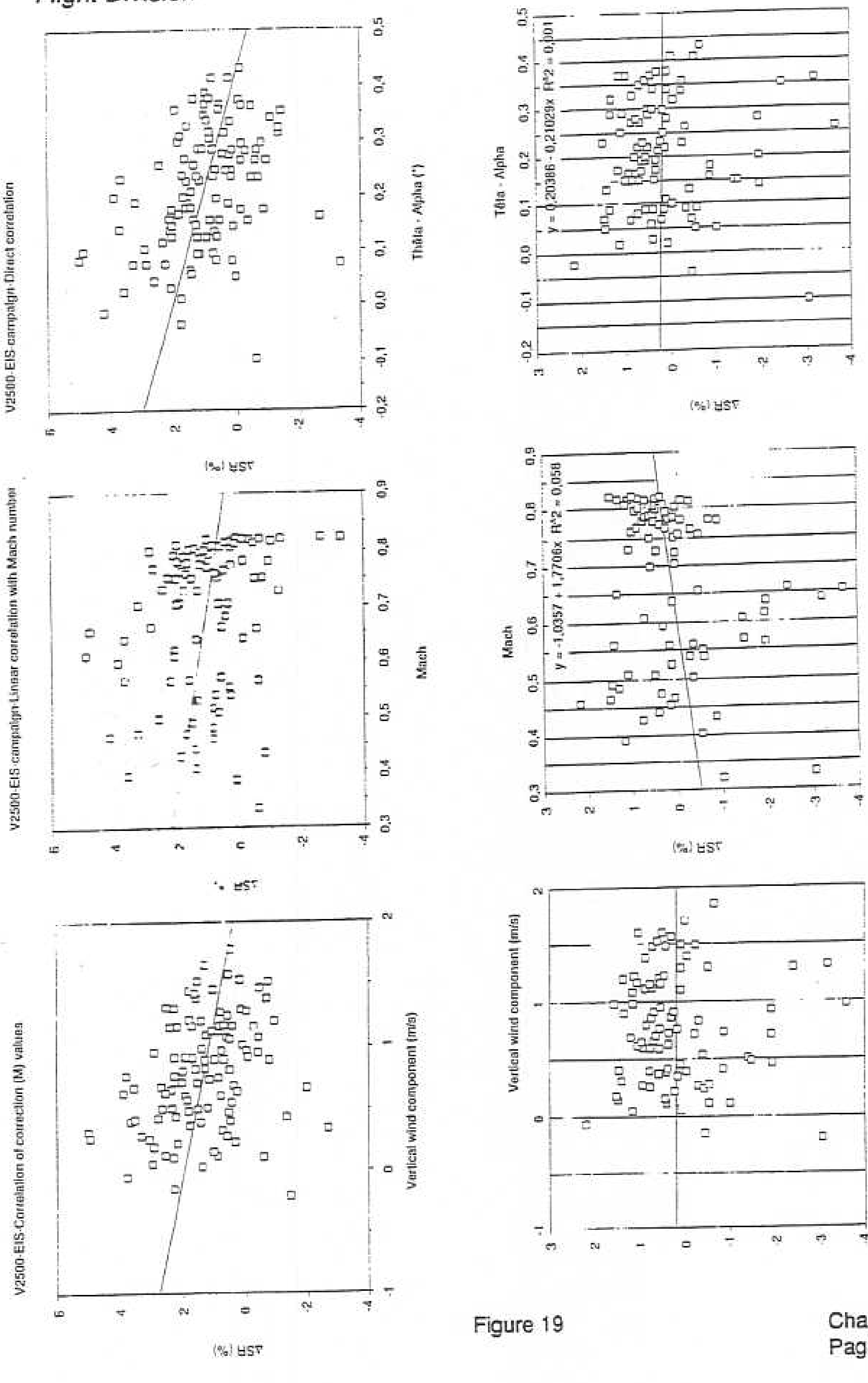

V2500-EIS-campaign-Direct correlation
Thêta - Alpha (°)
ΔSR (%)
V2500-EIS-campaign-Linear correlation with Mach number
Mach
V2500-EIS-Correlation of correction (M) values
Vertical wind component (m/s)
Thêta - Alpha
y = 0,20386 - 0,21029x R^2 = 0,001
A320 - V2500
y = -1,0357 + 1,7706x R^2 = 0,058
Mach
A320 - V2500
Vertical wind component (m/s)
A320 - V2500

Figure 19

3.3.2 Temperature gradient isobaric slope (Bias/Scatter)

Temperature gradients also modify the slope of the isobaric slope. For example, low pressure areas are cold compared to the high pressure areas, and the colder the low pressure, the steeper the isobaric surface slope.

Furthermore, the aircraft will be given a positive or negative compensation depending on the temperature gradient, the formulation of which was developed in the 1986 Conference. A graphic example is presented in Figure 17.

In audits, one would refrain from taking stabilized cruise performance readings with temperature gradients greater or equal to 1° C/6 minutes.

The usefulness of these corrections is, in fact, rather questionable since the theoretical assumptions are usually not applicable to the real atmosphere.

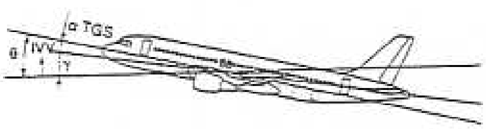
What we are looking for is the change in potential energy represented :

- by the slope of the flight path,
  and/or
- by the change of geopotential altitude.

However, when performing an assessment of this slope through the observed drift, and/or temperature trend, only the conditions at flight altitude are known (at best). For a correct application, conditions between, earth's surface and flight altitude are relevant ; this applies for both the assessment of a pressure-related slope as well as for a temperature-related slope.

There is presently no system which is capable of sensing flight path slope with the required accuracy (better than 0.002°). The only valuable approach today is to compute this slope from inertial information :

$$\sin\gamma = \frac{IVV}{TGS} \rightarrow \gamma$$



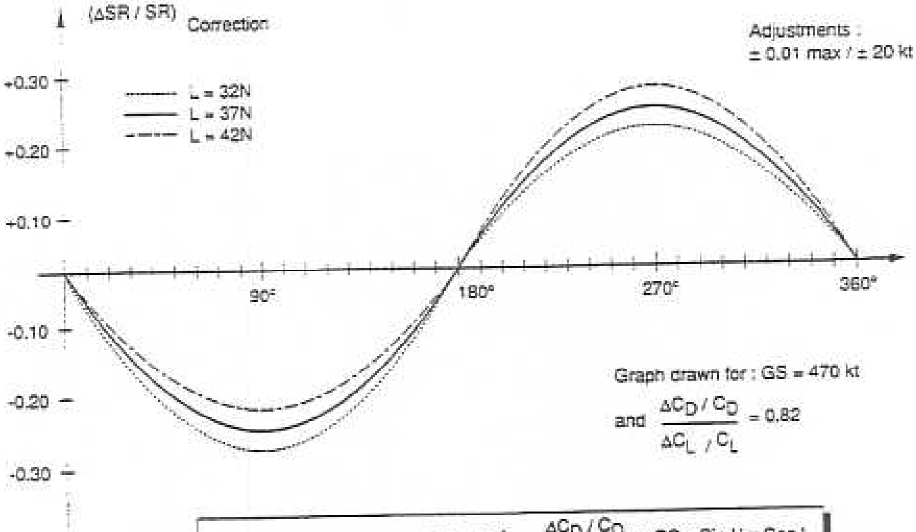
θ = pitch altitude
γ = flight path angle
(to ground)
α = angle of attack
IVV = inertial vertical velocity
TGS = true ground speed

This then would include all possible isobaric slope effects (pressure or temperature, geostrophic winds) without having to distinguish between these.

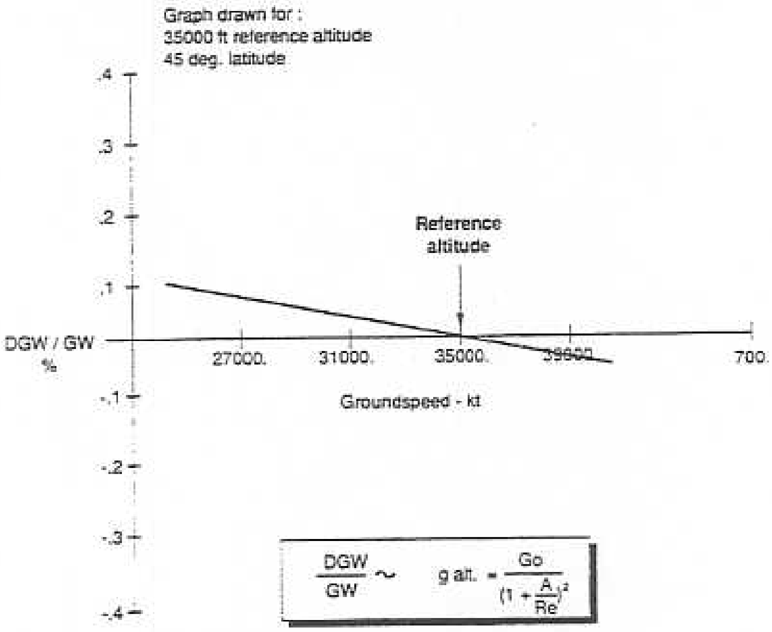
3.3.3 Vertical winds (Bias/Scatter)

The existence of significant vertical winds has been shown through :

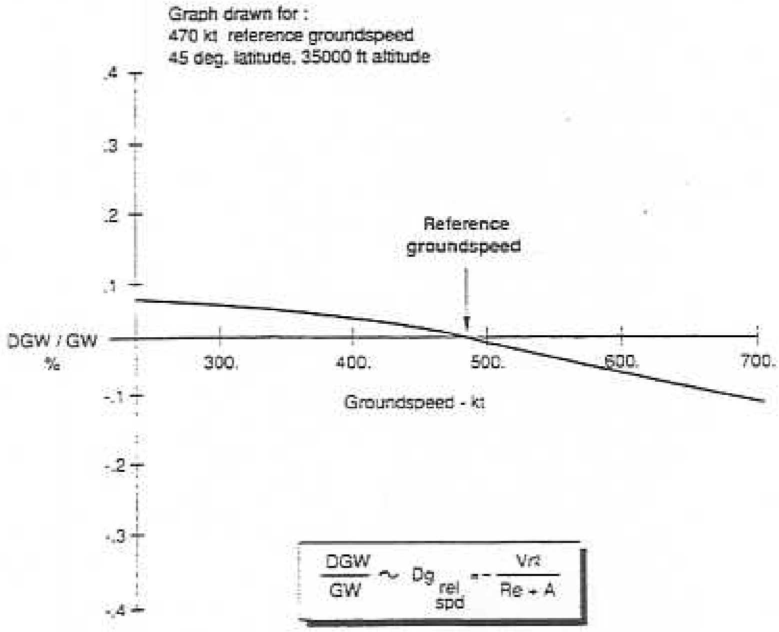
- divergence/difference effects
- speed changes
- temperature changes
- wave effects changing with altitude.



$$(\Delta SR/SR)_{Correction} = -7.63 \times 10^{-4} \times \frac{\Delta C_D / C_D}{\Delta C_L / C_L} \times GS \times \sin H \times \cos L$$



$$\frac{DGW}{GW} \sim g\ alt. = \frac{Go}{(1 + \frac{A}{Re})^2}$$



$$\frac{DGW}{GW} \sim Dg_{rel\ spd} = -\frac{Vr^2}{Re + A}$$

Figure 20

For the divergence situation, a coarse correlation of specific range with $\theta - \alpha$ was confirmed (remaining after correction of Mach effect). As shown in Figure 18, the scatter could be decreased after SR correction.

The mean value of vertical winds encountered was 0.6 m/second provided the alpha vane calibration can be trusted.

Current test procedures most probably do induce an unfavourable bias in cruise performance measurements because the crew usually concentrates on calm atmospheres. Extremely calm atmospheres necessarily correspond to subsiding (sinking) zones since these tend to increase stability. The problem is therefore to estimate the bias attributable to vertical winds. As things presently stand 0.17 m/second would correspond to a DSR of 1%, this exchange law being still under investigation.

Test criteria could consequently have to be revised ; it is suspected that audit/tests in a mildly agitated atmosphere rather than in a super calm one (with consequently subsidence-induced vertically sinking winds) would probably gather data of better quality.

3.3.4 Second-order effects (Coriolis, centrifugal acceleration, gravity) (Scatter)

All of these are programmed in the APM UNI-10 and help to decrease the data scatter. The three effects contribute to calculate actual aircraft weight from aircraft mass in the cruise performance report.

$$\underset{\text{Newton}}{\underset{\downarrow}{W_{A/C}}} = \underset{\text{kg}}{\underset{\downarrow}{\text{MASS}}} \left(Dg_{\text{coriolis}} + Dg_{\text{rel. spd}} + g_{\text{alt.}}\right)$$

Formulations having been expressed in the 1986Conference presentation, Figure 19 respectively illustrates Coriolis and centrifugal and gravity effects.

3.4 Technical factors

3.4.1 Lower heating value (Bias/Scatter)

The effect of fuel LHV on the apparent cruise performance level can best be understood by briefly recalling the physics concerning gas-turbine engine operation.

Fuel samples analysed in Aerospatiale laboratory using the ASTM D2382 METHOD,
" Standard Test Methods For Heat of Combustion of Hydrocarbon Fuels by Bomb Calorimeter (High-Precision Method)

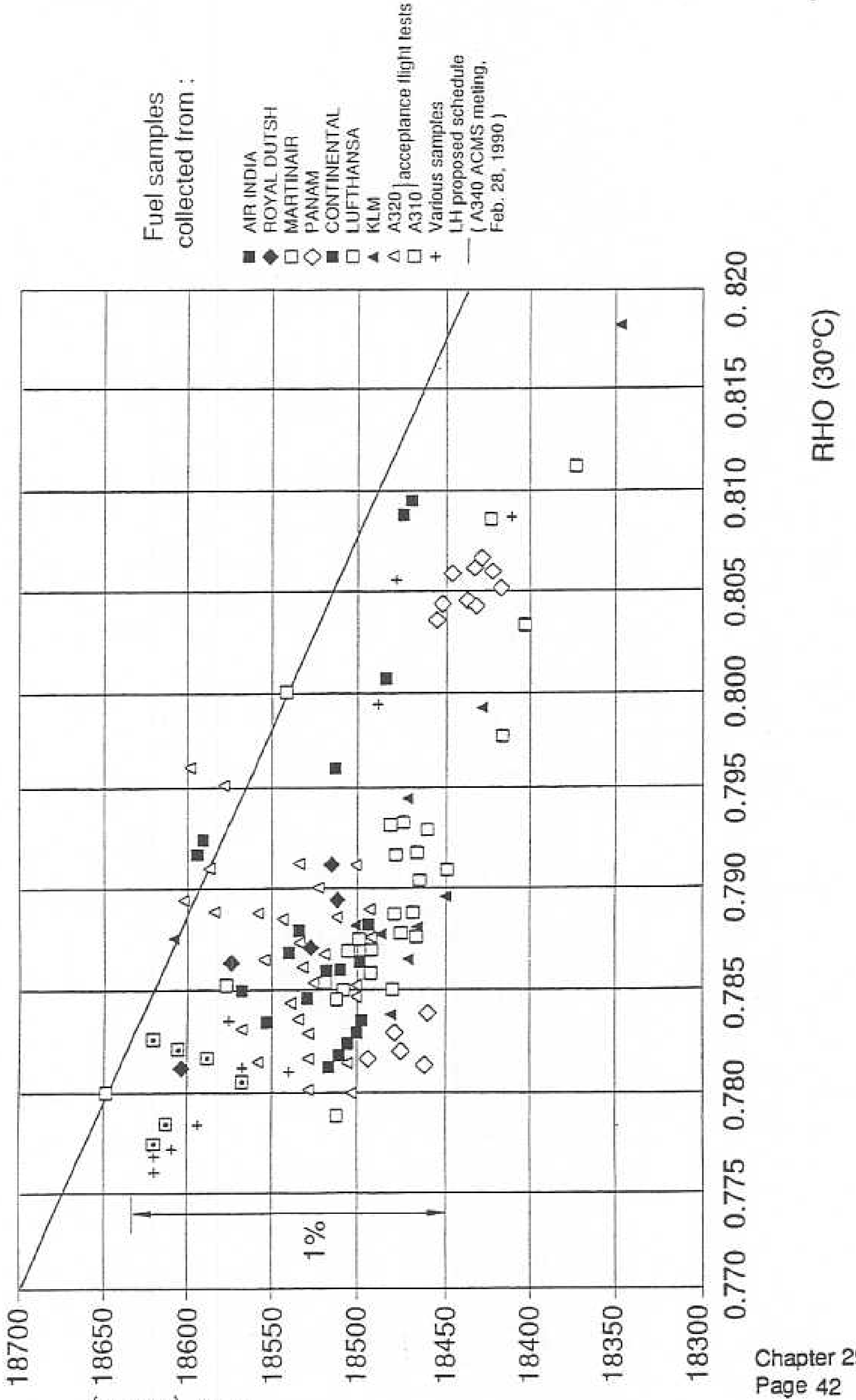


Figure 21

When having to maintain given flight conditions (weight, Mach, FL, TAT) to generate lift and drag, the engine has to produce a given thrust (N_1) provided a corresponding heat energy is developed in its combustion chamber.

$$Q = \underbrace{J}_{\text{physical constant}} \times Hf \times FF$$

Hf = fuel specific heat (LHV in BTU/lb)
FF = fuel flow (lb/h)

As of a consequence, the required fuel flow to produce the desired N_1 can be expressed as follows :

$$FF = \frac{Q}{J \times Hf} = \frac{1}{LHV} \times \frac{Q}{J}$$

Therefore, at a given required heat energy input Q, the lower the LHV, the higher the required fuel flow.

The fuel flow change - for a given LHV deviation - is such that the heat energy input remains constant :

$$FF \times LHV = \frac{Q}{J} = kt$$

As the heat energy input Q remains unchanged, with varying LHV, the engine thermo-dynamic cycle is also unchanged. As a consequence, the N_2 and EGT engine parameters remain unchanged.

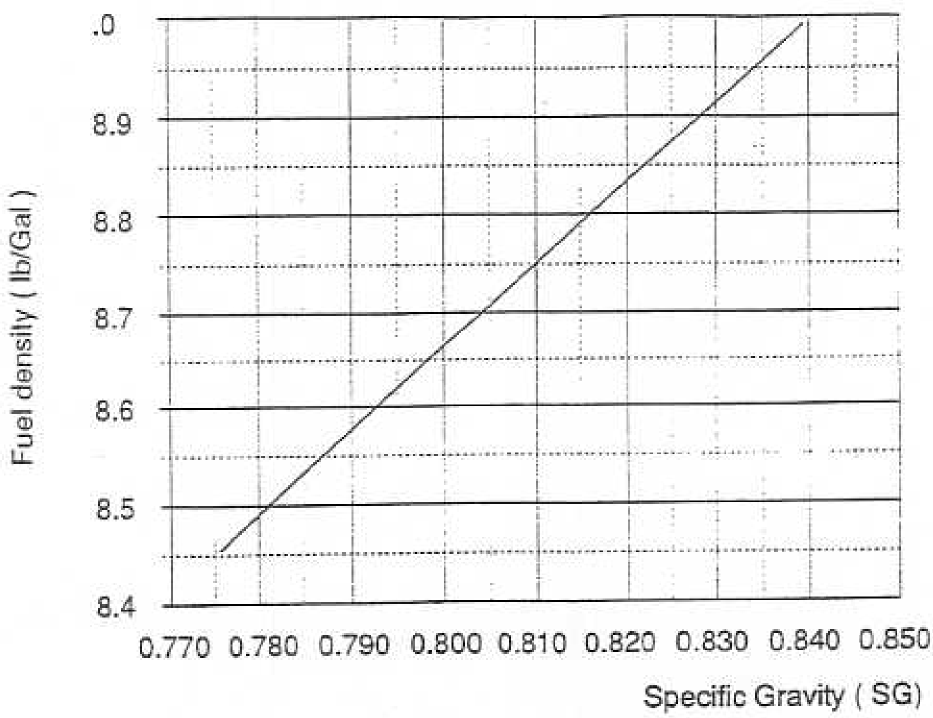
The only affected parameters are the FF and SR as follows :

$$\frac{\Delta FF}{\quad} = -\frac{\Delta LHV}{\quad}$$

$$\frac{\Delta SR}{SR} = +\frac{\Delta LHV}{LHV}$$

Various methods exist for LHV determination, the most prominent being the high-precision bomb calorimeter (Parr 1260) procedure specified by ASTM 2382-76 (re-approved 1980). Compared to ASTM 1405 (airline gravity method) and to ASTM D240 (simplified version of ASTM 2382) there appears to be a persistent bias of 0.8%, the overstimation of the two latter methods directly translating into a performance shortfall.

Fuel density vs. specific density - average of US fuel



LHV vs. specific density - average of US fuels

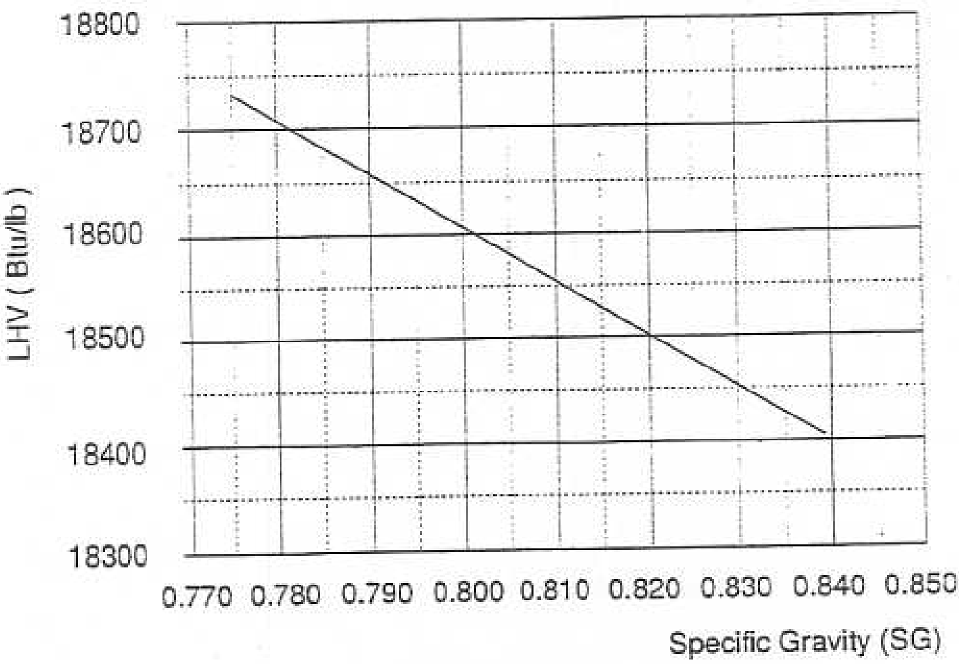


Figure 22

It is in any case essential to perform LHV measurements, as there exist wide variations in fuel quality throughout the world (crude oil quality) and between flights (refining product quality). Airbus Industrie/Aerospatiale now have a fairly extended data basis as they have been receiving lots of samples from their audits worldwide as shown in Figure 21.

A distinct difficulty lies in shipping fuel. Time and again, Airbus Industrie has to insist that airlines properly pack (IATA regulation on hazardous goods materials) and ship (through freight forwarder) fuel samples to Toulouse. Nevertheless shipments are also often delayed for administrative reasons and may never reach our home base.

When taking fuel samples, we sometimes suggest collecting a sample of remaining fuel (and corresponding quantity left) and a sample of tanked fuel (from bowser and corresponding quantity added) to determine a proportional average LHV. When on full tanks it may also be beneficial to determine fuel density at tank temperature to derive a better weight estimate. Figure 22 shows average relationships between specific gravity, and both fuel density and LHV from Western fuel samples.

3.4.2 Instrument accuracy (Bias/Scatter)

The most important aspect since the 1984 and 1986 Conferences concerns **fuel flow assessment.** In view of the A330/A340 programme, Airbus Industrie/Aerospatiale are currently improving their facilities to determine fuel flow with the best accuracy. The new rig allows :

- recording of all available calibration information
- control of actual engine fuel conditions
- control of the test section ambient conditions.

Fuel flow assessment procedures for production aircraft currently consist of equipping each engine :

- either with a volumetric flowmeter in line with the calibrated production massic flowmeter (development phase)
- or with a calibrated massic fuel flowmeter
- or with a standard (uncalibrated) massic fuel flowmeter.

Further information will by given in the future upon completion of the ongoing testing.

3.4.3 Data acquisition/transmission (Scatter/Bias)

Analysis of data recordings of an A320 Toulouse-Hamburg ferry flight confirmed the same problem as initially experienced with stability criteria of some A310 operators (where AIDS was BFE) : too stringent criteria on some aircraft parameters (IW, Roll, FPAC ...) resulting in too few engine cruise reports in A320 revenue service.

Consequently, a new set or "stable frame criteria" was developed for the A320 AIDS (Figure 24) similar to previous work presented at the Performance Monitoring Symposium held in Frankfurt 1985. This resulted in "opened windows" with respect to some aircraft parameters, the initial and re-adjusted values being shown in the following.

PARAMETERS	UNIT	DP LIMIT INITIALVALUES (1)	READJUSTEDDP LIMIT (2)
IVV	ft/min	100.	300
FPAC	g	0.012	0.03
ROLL	Deg	0.8	4.
TAT	Deg C	1.1	2.
N2	%	0.9	0.9
EGT	Deg C	18.	18.
VACC	g	0.03	0.1
MACH	-	0.008	0.01
N1	%	1.6	1.6
FF	KG/H	100.	100.
PT2	PSIA	0.05	0.1

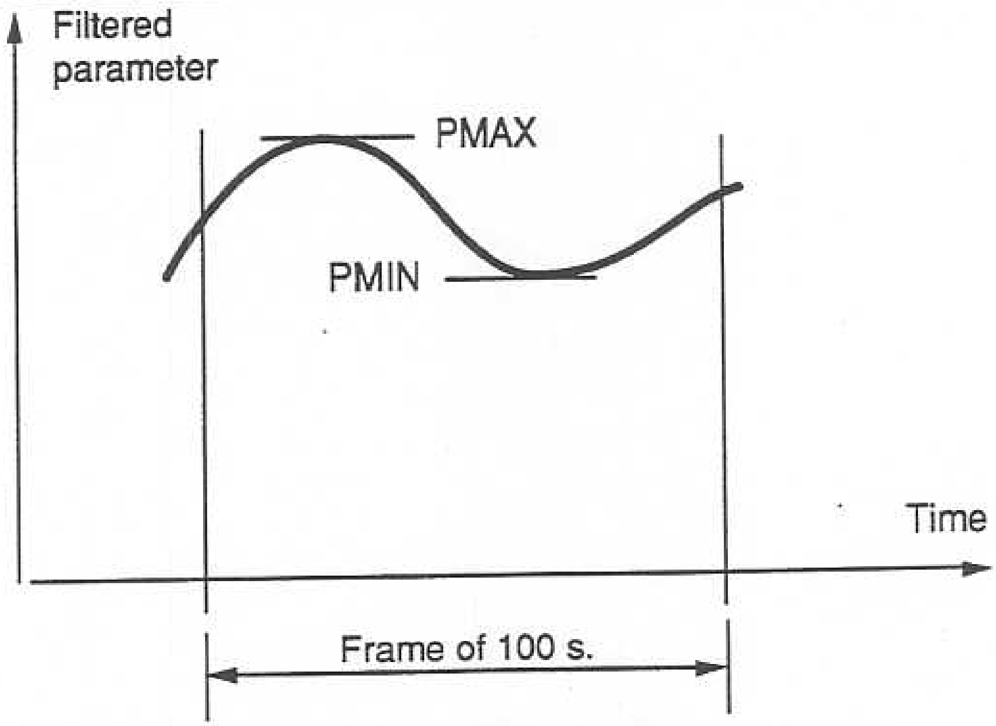
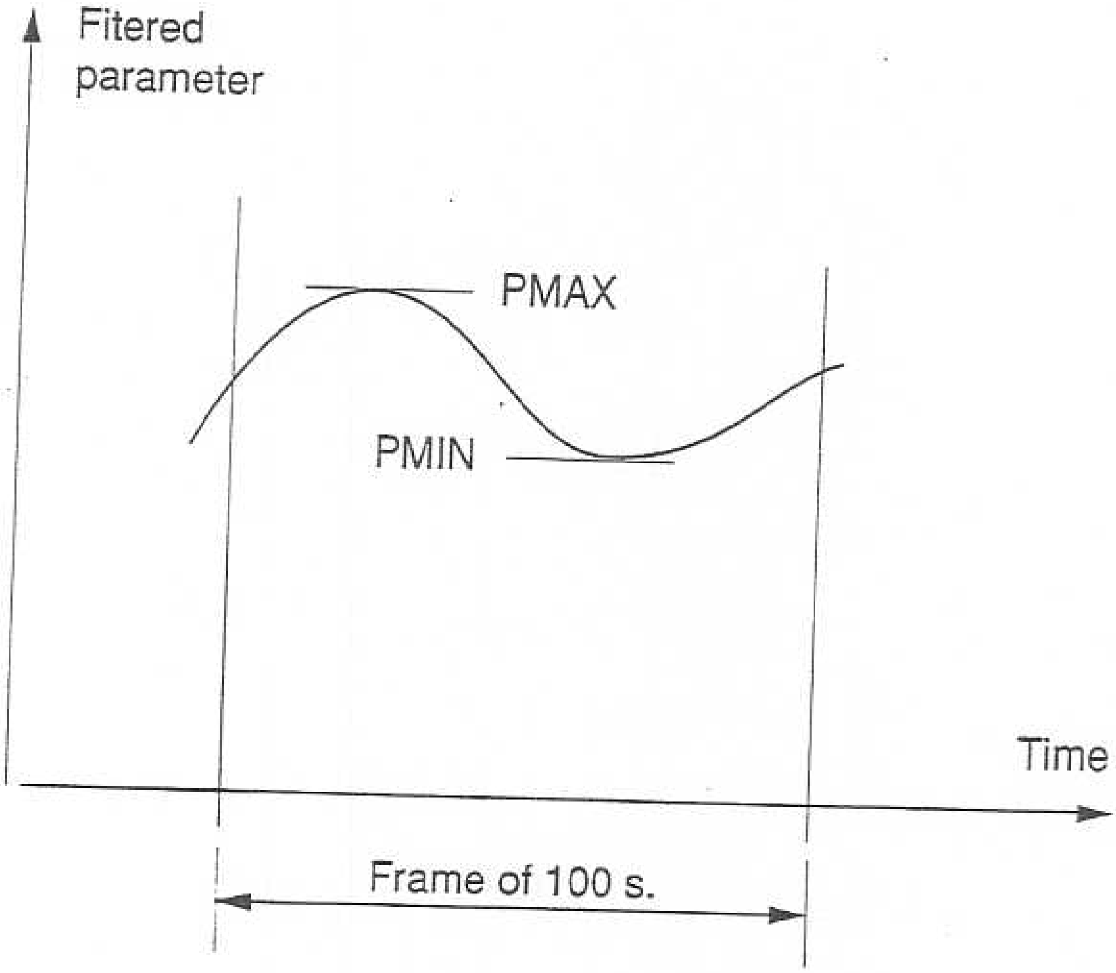


Figure 24 : **Stable frame = PMAX-PMIN < DP limit for all parameters (aircraft, engine 1 and engine 2) during this frame.**



Stable frame = PMAX-PMIN < DP limit for all parameters
(aircraft, engine 1 and engine 2) during this frame.

Figure 24

By way of example, when installed on a CFM56-5A1 engine, a flowmeter transducer functions with a fuel pressure of ≈20 bars and a fuel temperature of ≈75°C. Corrections have to be applied to take care of :

- fuel compressibility effects
- fuel thermal expansion
- flowmeter transducer thermal expansion.

They also need to be applicable to a relatively wide range of flow conditions.

Calibration done by another manufacturer has highlighted a large scatter and a bias of the indicated versus reference fuel flow in the cruise range (1000 to 1300 kg/h) (Figure 22)

120°F (48°C) fuel temperature ..... 1.1% ± 0.8% at 1200 kg/h
170°F (75°C) fuel temperature ..... 1.0% ± 0.8% at 1200 kg/h.

Calibration results will be available :

- in paper form at the test rig control
- in a data file, compatible with the ground data processing station, for further use.

3.4.3 Data acquisition/transmission (Scatter/Bias)

Analysis of data recordings of an A320 Toulouse-Hamburg ferry flight confirmed the same problem as initially experienced with stability criteria of some A310 operators (where AIDS was BFE) : too stringent criteria on some aircraft parameters (IW, Roll, FPAC ...) resulting in too few engine cruise reports in A320 revenue service.

Consequently, a new set or "stable frame criteria" was developed for the A320 AIDS (Figure 23) similar to previous work presented at the Performance Monitoring Symposium held in Frankfurt 1985. This resulted in "opened windows" with respect to some aircraft parameters, the initial and re-adjusted values being shown in the following.

PARAMETERS	UNIT	DP LIMIT INITIALVALUES (1)	READJUSTEDDP LIMIT (2)
IVV	ft/min	100.	300
FPAC	g	0.012	0.03
ROLL	Deg	0.8	4.
TAT	Deg C	1.1	2.
N2	%	0.9	0.9
EGT	Deg C	18.	18.
VACC	g	0.03	0.1
MACH	-	0.008	0.01
N1	%	1.6	1.6
FF	KG/H	100.	100.
PT2	PSIA	0.05	0.1

Following an A320 performance audit that used DMU printout recordings as APM inputs, an FPAC problem was suspected and subsequently confirmed. Pending further investigation of the origin of this problem (IRS, ...), it is pointed out that FPAC recording must for the present be zeroed (rather than using wrong values that would unduly contribute to scatter/bias).

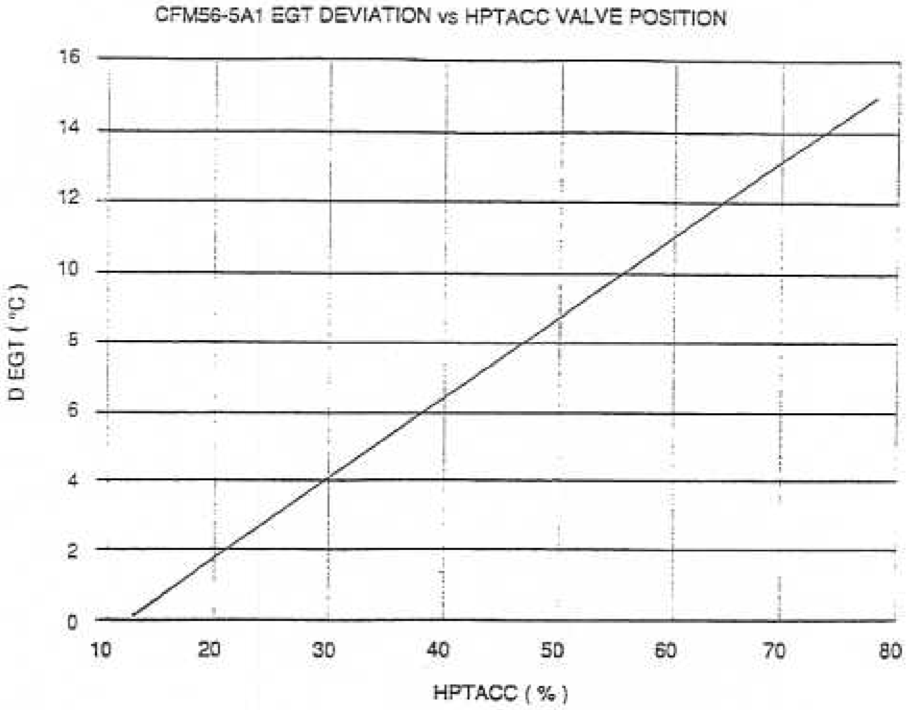
3.4.4 Engine effects/deterioration (Bias/Scatter)

The first engine regulation effects which were revealed in performance monitoring audits, concerned the Turbine Case Cooling System (TCCS). Inadvertent operation (at take-off and in climb due to baro switch malfunctions) caused the TCCS to cause case shrinking with ensuing turbine rub. Performance readings with and without TCCS activity (by pulling cockpit circuit breakers) allowed the extent of the performance loss to be estimated. When these readings resulted in the same DFF_2 APM outputs, this meant for instance that the full TCCS benefit had eroded (bias).

In a similar vein, Lufthansa last year informed Airbus Industrie of the high pressure turbine active clearance control (HPT ACC) valve position effect on engine performance. On A320, it appeared that about 40% of the DMU "stable cruise reports" were generated during the transition from climb to cruise phase and reflect the 9^{th} stage HPT ACC valve mode. Early cruise reports' APM results were biased and produced scatter. Besides the ability to disregard cruise reports gathered in early cruise (or to put a timer) another solution is to correct EGT and FF values (to their nominal according to the HPT ACC valve position as shown in the empirical graphs from CFMI in Figure 24.

Figure 24 shows the achievable magnitude of the scatter reduction by applying this correction when the valve is not in stabilized condition. The APM was amended to take this effect into account ; comparing the standard deviations of DFF_2 (DFF_{21} and DFF_{22}) and D SR without and with this correction confirms the significant improvement :

	without	with HPC ACC effect
DFF_{21}	2.30/1.00	1.92/0.49
DFF_{22}	5.25/1.15	4.89/0.57
D SR	- 4.38/0.65	- 4.16/0.22


CFM56-5A1 EGT DEVIATION vs HPTACC VALVE POSITION
D EGT (°C)
16
14
12
10
8
6
4
2
0
10
20
30
40
50
60
70
80
HPTACC (%)

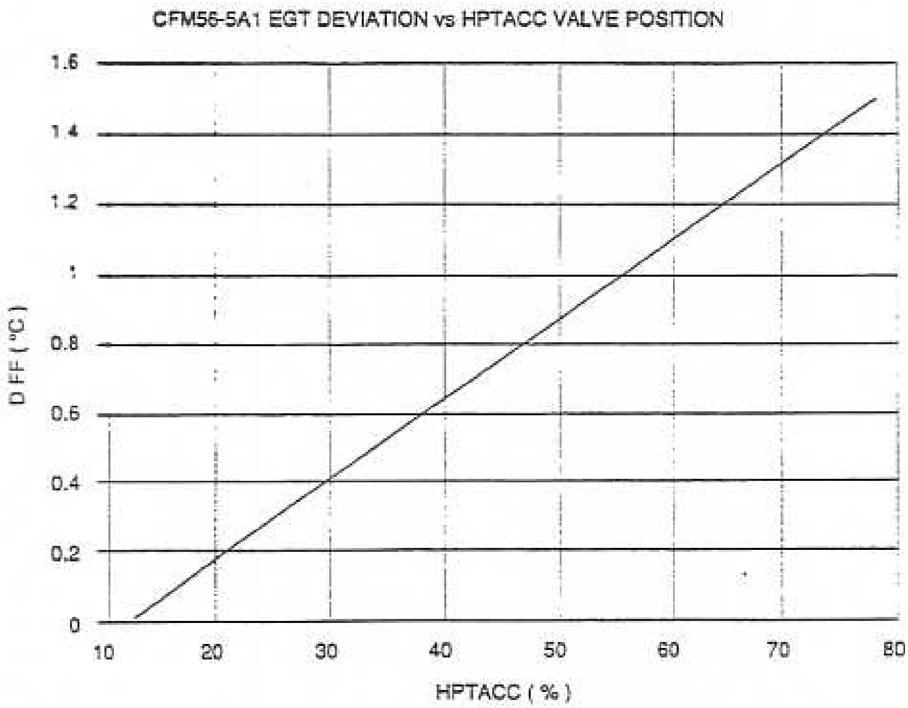

CFM56-5A1 EGT DEVIATION vs HPTACC VALVE POSITION
D FF (°C)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
70
80
HPTACC (%)

Figure 25

4. Conclusion

4.1 General precautions

In auditing, it is important to deal with these bias/scatter effects in the best way possible. The following measurement considerations/corrections factors are essential :

to avoid bias

- LHV
- weight, c.g.
- air conditioning/bleed selection options
- aircraft trimming
- instrument accuracy

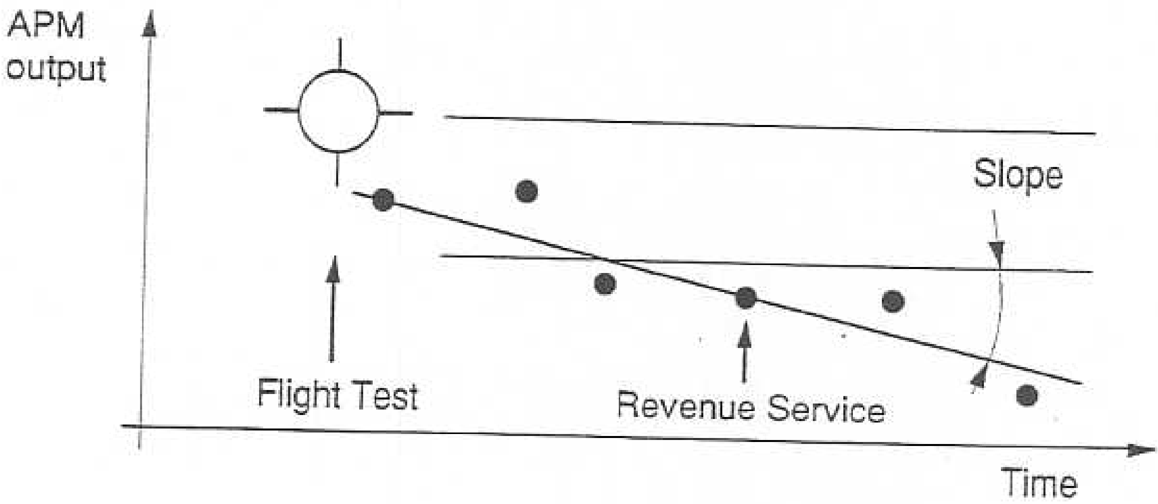
to reduce scatter

- data acquisition/ transmission
- instrument noise
- autothrottle/autopilot activity
- atmospheric influences
- stabilizer/elevator/trim

Figure 25 shows an exampe of a step wise approach to refining the analysis :

① raw data including CG, air conditioning (N)
② weight correction including increased carry-on baggage for ex-USA flights
③ ff calibration including acceptance data
④ LHV including fuel sampling results
⑤ OEW correction including manufacturers' aircraft weighing.

Figure 25 also shows a comparison of the D SR values at aircraft delivery, to derive a shift since service introduction. As no absolute measurements are possible in airline operations, it is important to follow the above-mentioned precautions as closely as possible : relative assessments will hence provide valuable trend information on the evolution of the aircraft's performance.



```
*** ENGINE SER.NO. L :                    *** DATA BASE :                                                                ***
*** ENGINE SER.NO. R :                        AERO    A320211    FROM  25/07/88  / GENERAL A120-211-00  FROM  25/07/88   ***
*** TAIL-NUMBER :                             ENGINE  A320211    FROM  17/06/91    TYPE     M565A1F                      ***
```

NO	DATE	FLNO	CASE	ALT	TAT	MACH	WEIGHT	CG	FPAC	VV	THDG	AT	VW1	DW1	ACT. W.
				FEET	C		KG	%	G	FT/MIN	DEG	DEG	KTS	DEG	N
1	61291	76	1	23985.	-7.8	0.791	53800.	24.6	-0.0005	0.0	3.	11.	65.	7.	526256.
2	71291	194	1	36975.	-37.6	0.789	54500.	24.9	-0.0010	0.0	223.	18.	36.	340.	533091.
3	81291	68	1	24001.	-10.7	0.714	58300.	31.9	0.0000	0.0	21.	11.	47.	24.	569968.
4	101291	1383	1	34773.	-40.4	0.782	54600.	31.1	-0.0015	0.0	----	----	----	----	535443.
5	111291	984	1	29005.	-22.5	0.795	58300.	31.6	-0.0005	0.0	----	----	----	----	571728.
6	121291	32	1	17000.	1.0	0.659	55800.	30.2	-0.0005	0.0	----	----	----	----	547211.
7	131291	114	1	22976.	-4.2	0.719	60300.	30.4	0.0000	-0.1	----	----	----	----	591341.
8	171291	1698	1	27980.	-17.5	0.752	59000.	34.7	-0.0020	-0.1	321.	51.	60.	1.	577658.

NO	BL	WBL1	WBL2	N11	N12	FFA1	FFA2	FLHVR	N1TH	FFTH	FFC1	FFC2	DN11	DN12	DFF11	DFF12	DFF21	DFF22	DSR
		--- KG/S ---		---- % -----		--- KG/H ---			%	------ KG/H -------			----------- % -----------						
1	N	----	----	85.6	85.6	1662.	1708.	1.000	85.2	1612.	1643.	1643.	0.44	0.44	1.90	1.90	1.18	3.98	-4.33
2	N	----	----	84.7	84.7	1044.	1077.	1.000	84.7	1028.	1029.	1029.	0.03	0.03	0.13	0.13	1.46	4.67	-3.10
3	N	----	----	82.0	82.0	1394.	1441.	1.000	81.9	1345.	1348.	1348.	0.05	0.05	0.23	0.23	1.38	6.86	-5.09
4	N	----	----	82.9	82.9	1075.	1106.	1.000	82.7	1042	1053.	1053.	0.22	0.22	1.01	1.01	2.11	5.06	-4.43
5	N	----	----	85.0	85.0	1405.	1443.	1.000	84.7	1366.	1384.	1384.	0.29	0.29	1.34	1.34	1.53	4.27	-4.10
6	N	----	----	79.1	79.1	1532.	1577.	1.000	79.1	1474.	1472.	1472.	-0.03	-0.03	-0.13	-0.13	4.09	7.15	-5.20
7	N	----	----	83.2	83.2	1482.	1524.	1.000	83.0	1434.	1447.	1447.	0.21	0.21	0.87	0.87	2.44	5.34	-4.57
8	N	----	----	83.5	83.5	1307.	1343.	1.000	83.3	1269.	1279.	1279.	0.17	0.17	0.80	0.80	2.20	5.02	-4.25
										MEAN VALUE			0.17	0.17	0.77	0.77	2.30	5.29	-4.38
										STANDARD DEVIATION			0.15	0.15	0.67	0.67	1.00	1.15	0.65

NO	BL	WBL1	WBL2	N11	N12	FFA1	FFA2	FLHVR	N1TH	FFTH	FFC1	FFC2	DN11	DN12	DFF11	DFF12	DFF21	DFF22	DSR
		--- KG/S ---		---- % -----		--- KG/H ---			%	------ KG/H -------			----------- % -----------						
1	N	----	----	85.6	85.6	1662.	1708.	1.000	85.2	1612.	1643.	1643.	0.44	0.44	1.90	1.90	1.18	3.98	-4.33
2	N	----	----	84.7	84.7	1044.	1077.	1.000	84.7	1028.	1029.	1029.	0.03	0.03	0.13	0.13	1.46	4.67	******
3	N	----	----	82.0	82.0	1394.	1441.	1.000	81.9	1363.	1365.	1367.	0.05	0.05	0.16	0.29	2.10	5.40	-3.84
4	N	----	----	82.9	82.9	1075.	1106.	1.000	82.7	1042.	1053.	1053.	0.22	0.22	1.01	1.01	2.11	5.06	-4.43
5	N	----	----	85.0	85.0	1405.	1443.	1.000	84.7	1366.	1384.	1384.	0.29	0.29	1.34	1.34	1.53	4.27	-4.10
6	N	----	----	79.1	79.1	1532.	1577.	1.000	79.1	1494.	1492.	1492.	-0.03	-0.03	-0.13	-0.13	2.69	5.71	-3.91
7	N	----	----	83.2	83.2	1482.	1524.	1.000	83.0	1439.	1452.	1452.	0.21	0.21	0.87	0.87	2.09	4.98	-4.25
8	N	----	----	83.5	83.5	1307.	1343.	1.000	83.3	1269.	1279.	1279.	0.17	0.17	0.80	0.80	2.20	5.02	-4.25
										MEAN VALUE			0.17	0.17	0.76	0.78	1.92	4.89	-4.16
										STANDARD DEVIATION			0.15	0.15	0.68	0.67	0.49	0.57	0.22

** 95 % CONFIDENCE :
THE 5% VALUES OUT OF RANGE (MEAN+- 2*SIGMA) ARE SET TO "*" AND ARE NOT INCLUDED IN THE FINAL MEAN VALUE AND STANDARD DEVIATION

Figure 26

4.2 Trends and factoring

Two independent trend studies based on A300 aircraft were presented at the 1984 Conference and at the 1985 Conference on Performance Monitoring. The first analysis did not consider maintenance actions and concerned some 6 years of operations where all these effects (airframe, engines, instruments) were embedded into deterioration patterns. Least squares over APM outputs indicated :

- D SR/year = - 0.3%
- D FF_2/year = +0.3%

The second analysis did consider maintenance effects on an 11-aircraft fleet covering a 10-month period. Ample knowledge of most engine and aerodynamics related maintenance work (17 engine changes) indicated :

- $D\,SR_{\text{after engine change}} - D\,SR_{\text{before}}$ = 0.7% — step improvement at engine change
- D SR/year = - 0.3% — annual trend when changing engines
- D SR/year = - 1.3% — annual trend when not changing engine

In a more recent third study statistical hypothesis (Student t-test) testing was performed on paired fleet average of APM outputs ($DN1_{\text{before}}/DN1_{\text{after}}$; $DFF11_{\text{before}}/DFF11_{\text{after}}$; ... $DFF22_{\text{before}}/DFF22_{\text{after}}$; $D\,SR_{\text{before}}/D\,SR_{\text{after}}$)

This survey covered a fleet of 14 aircraft over a period of 26 months during which 40 engine changes were performed as well as 20 airframe-related actions, and reflected the impact of the airline's maintenance policy :

▲ the poor likelyhood (< 0.5% chance) that this airline's engine changes do not improve specific range (+ 0.5%) and that these do not decrease fuel consumption (DFF_2) (- 1%)

▲ the high likelyhood (> 95% chances) that this airline's airframe work does not significantly improve specific range, DN_1 and related fuel consumption (DFF_1).

Trends can therefore provide essential information concerning the impact of a maintenance policy provided adequate bookkeeping is performed to record :

- numeric APM outputs before and after maintenance actions,
- strategic maintenance actions (airframe, engines, instruments).

Deteriorating from delivery, individual aircraft SR trends compared to the manufacturer's baseline provide the performance factor that is eventually entered into that aircraft's FMS for fuel padding.

	DN_{11}	DN_{12}	DFF_{11}	DFF_{12}	DFF_{21}	DFF_{22}	DSR	DSR DELIVERY
① RAW DATA								
Mean value	0.30	0.31	1.24	1.31	3.15	3.47	- 4.40	
St. deviation	0.32	0.33	1.33	1.35	0.34	0.29	1.42	
② WEIGHT CORR								
Mean value	- 0.10	- 0.09	- 0.42	- 0.37	3.18	3.62	- 2.91	
St. deviation	0.09	0.10	0.38	0.40	0.23	0.17	0.36	
③ FF CALIB CORR								
Mean value	- 0.10	- 0.09	- 0.42	- 0.38	2.95	2.31	- 2.17	
St. deviation	0.08	0.10	0.35	0.41	0.19	0.05	0.38	
④ LHV								
Mean value	- 0.10	- 0.09	- 0.42	- 0.38	2.45	1.82	- 1.69	- 1.04 D(DSR) - 0.65
St. deviation	0.08	0.10	0.35	0.41	0.19	0.05	0.38	
⑤ OEW CORR								
Mean value	- 0.27	- 0.26	- 1.10	- 1.06	2.45	1.82	- 1.02	D(DSR) ≈ 0
St. deviation	0.08	0.09	0.34	0.40	0.19	0.05	0.37	

Figure 27

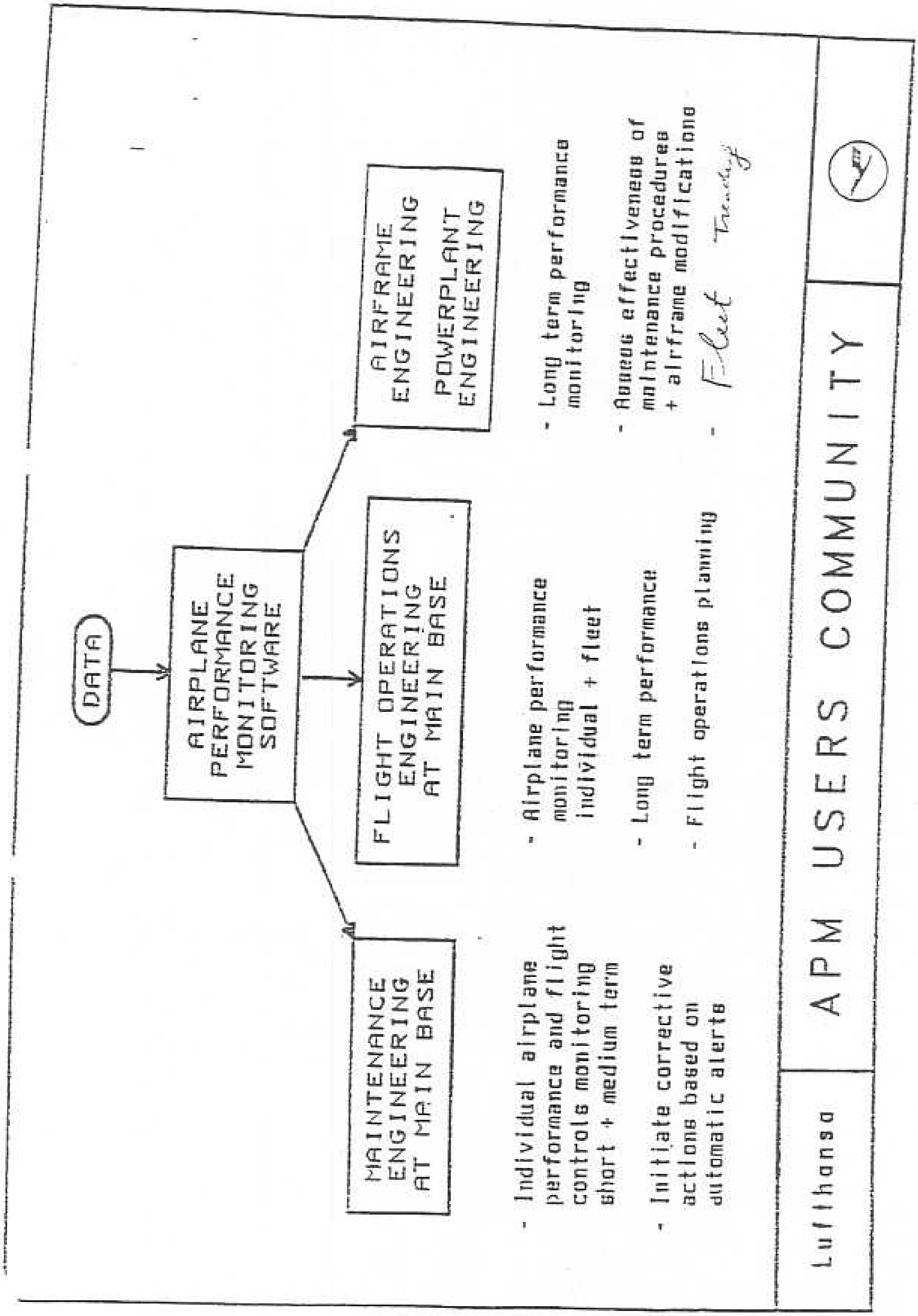

DATA
AIRPLANE PERFORMANCE MONITORING SOFTWARE
MAINTENANCE ENGINEERING AT MAIN BASE
FLIGHT OPERATIONS ENGINEERING AT MAIN BASE
AIRFRAME ENGINEERING
POWERPLANT ENGINEERING
- Individual airplane performance and flight controls monitoring short + medium term
- Initiate corrective actions based on automatic alerts
- Airplane performance monitoring individual + fleet
- Long term performance
- Flight operations planning
- Long term performance monitoring
- Assess effectiveness of maintenance procedures + airframe modifications
- Fleet Trending
APM USERS COMMUNITY
Lufthansa

Figure 28

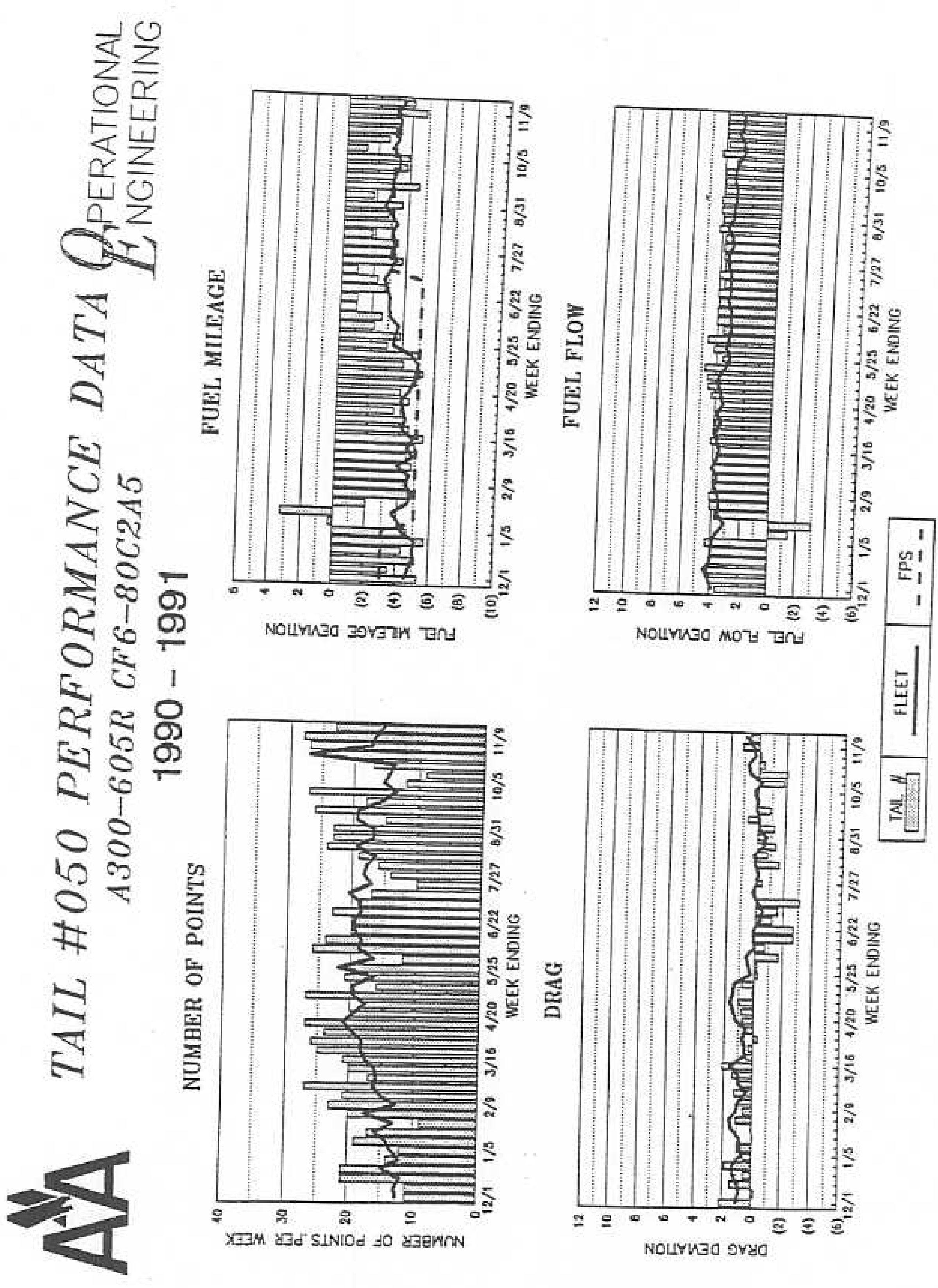

TAIL #050 PERFORMANCE DATA
A300-605R CF6-80C2A5
1990 - 1991
OPERATIONAL ENGINEERING
NUMBER OF POINTS
NUMBER OF POINTS PER WEEK
FUEL MILEAGE
FUEL MILEAGE DEVIATION
DRAG
DRAG DEVIATION
FUEL FLOW
FUEL FLOW DEVIATION
WEEK ENDING
TAIL #
FLEET
FPS

Figure 29

4.3 APM systems

This paper has outlined the underlying principles and recommended procedures to obtain the most out of each performance monitoring method. It is then up to the operators to integrate whatever method selected into their routine trending bearing in mind :

- the airline's expectations of the monitoring tool
- the airline's needs and means.

Figure 26 shows the elaborate Lufthansa approach which aims at a maximum of applications (operations, maintenance, engineering).

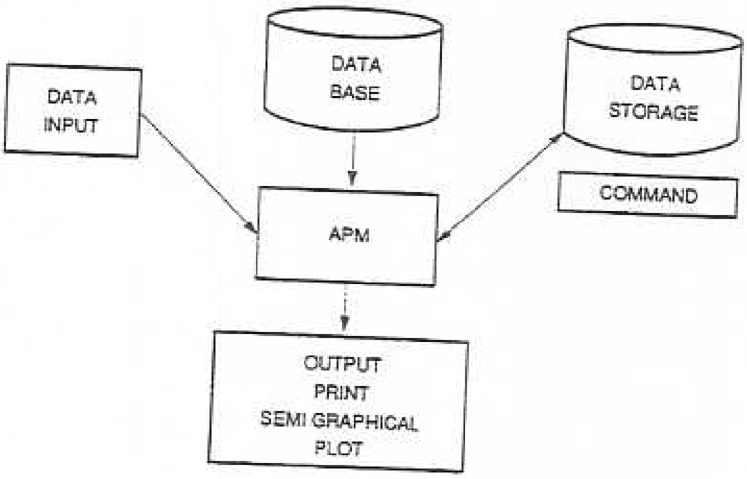


Figure 30

Figure 27 shows the comprehensive American Airlines trending pilots resulting from that airline's APM systems. This system can be explained by with the following flow chart :

Airbus Industrie has, for its part, developed an APM system for both mainframe and personal computer applications, which offers the ability :

- to have one program suitable to the whole AI fleet
- to minimize the impact of the new system on existing interfaces
- to provide a modular evolutive system adaptable in the airline environment.

This system depicted in the following will, moreover, offer the capabilities required for fleet trending :

- storage
- compression
- smoothing
- semi-graphical pilotting.

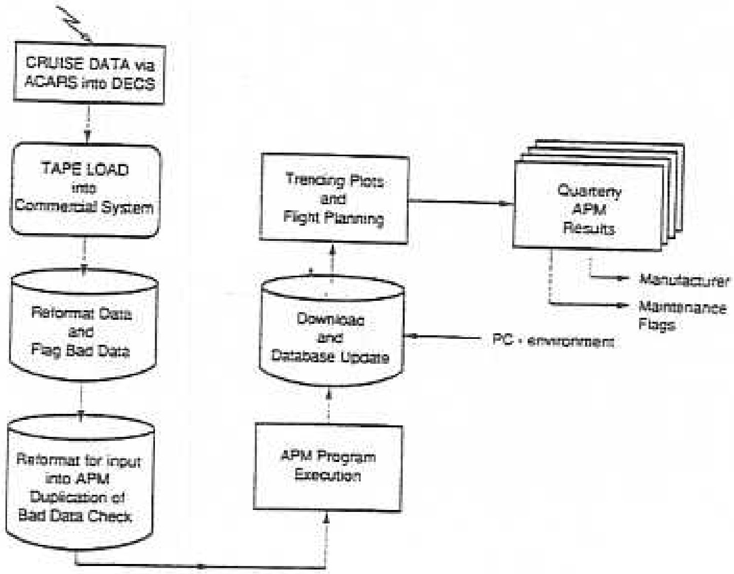


Figure 31

Airbus Industrie would be eager to work with some airlines on an ongoing application of this projected APM system well in advance of its anticipated use on the A330/A340 programs.

LEFT INTENTIONALLY BLANK

I. GLOSSARY

Greek letters

α	(alpha)	Angle of attack
γ	(gamma)	Climb or descent angle
δ	(delta)	Pressure ratio = P / P_0
Δ	(DELTA)	Parameters' variation (ex : ΔISA, ΔP)
ϕ	(phi)	Bank angle
θ	(theta)	Aircraft attitude
ρ	(rho)	Air density
ρ_0	(rho zero)	Air density at Mean Sea Level
σ	(sigma)	Air density ratio = ρ / ρ_0

A

ACARS	Aircraft Communication Addressing and Reporting System
ADIRS	Air Data / Inertial Reference System
ADIRU	Air Data/Inertial Reference Unit
AFM	Aircraft Flight Manual
AIDS	Aircraft Integrated Display System
ALD	Actual Landing Distance
AMC	Acceptable Means of Compliance (JAA)
AMJ	Advisory Material Joint (JAA)
AOM	Airline Operation Manual
APM	Aircraft Performance Monitoring (program)
APU	Auxiliary Power Unit
ARMS	Aircraft Recording and Monitoring System
ATC	Air Traffic Control
ATSU	Air Traffic Service Unit

B

BITE	Built In-Test Equipment

C

CFDIU	Centralized Fault Display Interface Unit
CFDS	Centralized Fault Display System
CAS	Calibrated Air Speed
CG	Center of gravity
CI	Cost Index

D

DA	Drift Angle
DAR	Digital AIDS/ACMS Recorder
	Optional recorder
DGAC	Direction Générale de l'Aviation Civile
DITS	Digital Information Transfer System
DMU	Data Management Unit
DOC	Direct Operating Cost
DOW	Dry operating weight

E

ECON	Economic (minimum cost) speed
EGT	Exhaust Gas Temperature
EPR	Engine Pressure Ratio
ETOPS	Extended range with Twin engine aircraft OPerationS

F

f( )	Function of ( )
FAA	Federal Aviation Administration
FAC	Flight Augmentation Computer
FAR	Federal Aviation Regulation
FBW	Fly-By-Wire (aircraft)
FCOM	Flight Crew Operating Manual
FDIU	Flight Data Interface Unit
FDRS	Flight Data Reporting System
	Mandatory parameters
FF	Fuel Flow (hourly consumption)
FL	Flight Level
FLIP	Flight Planning (program)
FMGS	Flight Management and Guidance System
FOB	Fuel On Board
FQI	Fuel Quantity Indicator
FWC	Flight Warning Computer

G

g	Gravitational acceleration
GAL	US gallon
GDS	Green Dot speed
GS	Ground Speed

H

hPa	hecto Pascal

I

IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
IFP	In Flight Performance (program)
IFR	Instrument Flight Rules
IL	Information Leaflet (JAA)
IMC	Instrument Meteorological Conditions
in Hg	Inches of mercury
ISA	International Standard Atmosphere

J

JAA	Joint Aviation Authority
JAR	Joint Airworthiness Requirements

K

Ki	Instrumental correction (Antenna error)

L

LAT	Latitude
LPC	Less Paper Cockpit (program)
LRC	Long Range Cruise speed

M

M_{LR}	Mach of Long Range
M_{MR}	Mach of Maximum Range
M_{MO}	Maximum Operating Mach number
MCDU	Multipurpose Control and Display Unit
MDDU	Multipurpose Disk Drive Unit
MCT	Maximum Continuous Thrust
MEL	Minimum Equipment List
MES	Main Engine Start
MEW	Manufacturer Empty Weight
MSL	Mean Sea Level
MTOW	Maximum TakeOff Weight
MTW	Maximum Taxi Weight
MZFW	Maximum Zero Fuel Weight

N

n	Load factor
n_z	Load factor component normal to the aircraft's longitudinal axis
N1	Speed rotation of the fan
NLC	Noise Level Computation (program)
NPA	Notice for Proposed Amendment (JAA)
NPRM	Notice for Proposed Rule Making (FAA)

O

OAT	Outside Air Temperature
OCTOPUS	Operational and Certified Takeoff and landing Universal Software
OEW	Operational Empty Weight
OFP	Operational Flight Path (program)

P

P	Pressure
P_0	Standard pressure at Mean Sea Level
PEP	Performance Engineering Programs
PFD	Primary Flight Display

Q

QAR	Quick Access Recorder Optional equipment

S

SAR	Smart Access Recorder Internal DMU/FDIMU memory
SAT	Static Air Temperature
SFC	Specific Fuel Consumption
SR	Specific Range
SSFDR	Solid State Flight Data Recorder
SSMM	Solid State Mass Memory
STD	Standard

T

T	Temperature
T_0	Standard temperature at Mean Seal Level
T_{ISA}	Standard temperature
T_{REF}	Flat Rating Temperature
TAS	True Air Speed
TAT	Total Air Temperature
TLC	Takeoff and Landing Computation (program)
TLO	TakeOff and Landing Optimization (program)
TOGA	TakeOff / Go-Around thrust
TOW	TakeOff Weight

V

V	Velocity
V_{LS}	Lowest selectable speed
V_{MO}	Maximum Operating speed
V_S	Stalling speed
V_{S1G}	Stalling speed at one g
V_{SR}	Reference stalling speed
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

W

W	Weight
Wa	Apparent weight
WC	Wind component

Z

ZFW	Zero Fuel Weight

LEFT INTENTIONALLY BLANK

J. BIBLIOGRAPHY

[J-1] 7th Performance and Operations Conference – "Auditing aircraft cruise performance in airline revenue service", Jean Jacques SPEYER, Airbus Flight Operations & Line Assistance, STL. Leading article appended to this brochure (Appendix 6).

[J-2] Performance Programs Manual

[J-3] "Getting hands-on-experience with aerodynamic deterioration" Airbus brochure, reference STL 945.3399/96, October 2001, Issue 2.

For any comment, suggestion, or enquiry concerning this brochure please contact the Airbus Customer Services, Flight Operations Support & Line Assistance department (STL)
Fax: +33 561 93 29 68/44 65,
E-mail : account.fops@airbus.com

AIRBUS

31707 Blagnac Cedex
France

Ref.: STL 94B.0510/02

AIRBUS

AIRBUS S.A.S.
31707 BLAGNAC CEDEX - FRANCE
CONCEPT DESIGN SCM12
REFERENCE SCM1-D388
DECEMBER 2002
PRINTED IN FRANCE

AN EADS JOINT COMPANY
WITH BAE SYSTEMS

Flight Operations Support & Line Assistance

getting to grips with aircraft performance monitoring

December 2002