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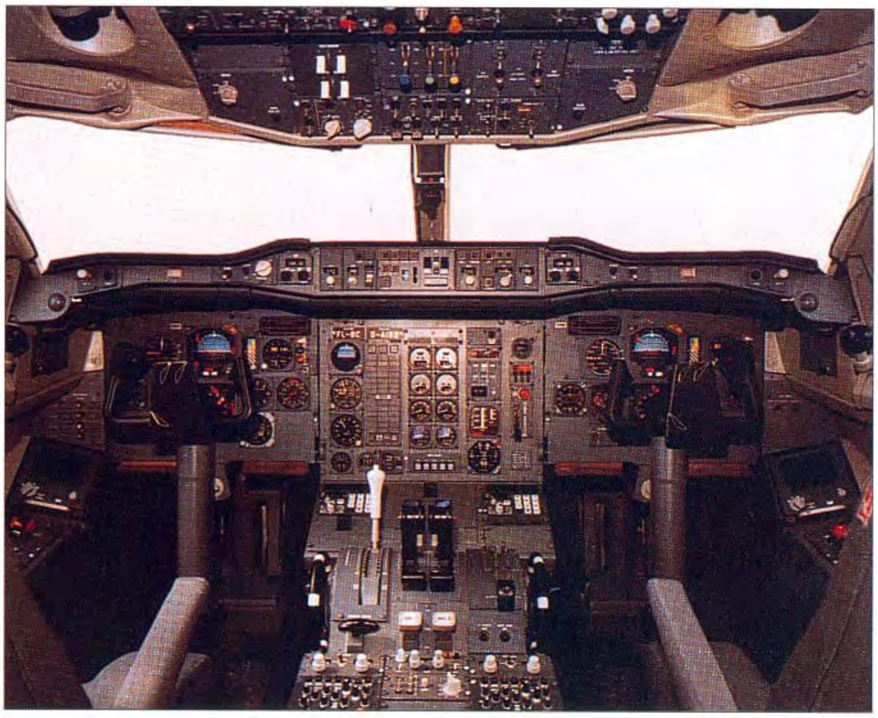
ADVANCED TECHNOLOGY AND THE PILOT

by William A. Wainwright
Test Pilot Airbus Industrie

AS PROGRESS HAS BEEN MADE IN INCORPORATING ADVANCES AND TECHNOLOGY INTO NEW AIRCRAFT DESIGNS, MANY PEOPLE HAVE QUESTIONED WHETHER THE NEEDS OF THE HUMAN BEING HAVE BEEN FORGOTTEN IN THE QUEST TO AUTOMATE. SOME HAVE EVEN SUGGESTED THAT MANUFACTURERS ARE MOVING TOWARDS THE PRODUCTION OF PILOTLESS AIRLINERS. AT AIRBUS INDUSTRIE HOWEVER WE BELIEVE THAT TECHNOLOGY IS BEST USED TO GIVE THE HUMAN BEING A ROLE FOR WHICH HE IS SUITED, TAKING INTO ACCOUNT HIS STRENGTHS AND WEAKNESSES. WE ALSO BELIEVE IN MOVING STEP BY STEP. THE A320 FAMILY, AND A330/A340 ARE NATURAL EVOLUTIONS FROM THE A300 AND A310 DESIGNS.

▲ *A340 cockpit with Pierre Baud, Airbus Industrie's Chief Pilot, in command.*



Inside the cockpits: *A300* ▲
A310 ▶
A320 ▼

The Airbus attitude to automation is to use technology to give back to the pilot his traditional task of flight path control and general flight management. Automatic systems are used to match the flow of information to the need of the pilot, and to automate tasks for which human beings are ill-suited. Systems and Navigation Aids are designed so that the pilot only has the same level of involvement as on classic aircraft, on which he was accompanied by a Navigator and Flight Engineer. Automatic monitoring relieves him of a task for which he is ill-suited, and reliance on memory and paper is reduced: the information display shows him what he needs to know, when he needs to know it.

Finally, Fly-By-Wire makes a large aircraft a delight to fly; light on the controls, responsive and precise.

HUMAN FACTORS CONSIDERATIONS

There are many human factors and it is not the purpose of this article to address all of them, but it is of interest to highlight the following pertinent ones which are particularly relevant to the evolution of our design.

The aircraft must be easy to operate in both manual and automatic modes. Automatic flight guidance must be fully capable from lift-off to the end of the landing roll, thereby offering the pilot the option to use it at any stage of flight with confidence that it will perform well. It must also have a good man/machine interface, so that using it does not increase the workload; this demands that system logic must be in accordance with human thinking. Reversion between automatic and manual control must be simple and easy to achieve, and manual flight should be as easy as using the autopilot - otherwise it becomes a degraded mode of operation with an associated high workload. Finally, the role given to the pilot takes into account known deficiencies in human performance, such as poor long-term monitoring capability and limited working memory.

AIRBUS AND AUTOMATION

The history of automation in civil airliners is dominated by three considerations. Firstly, technical considerations meant that one could automate what could be automated - which in the beginning of jet transportation, was not very much in comparison with today. Secondly, safety considerations led to the automation of those tasks which had produced "pilot error". Thirdly, financial considerations caused automation to be introduced where it could bring improvements in performance, and thus cost benefits. But we are now at the stage where we can automate almost anything that we wish to automate. Our philosophy is to use human considerations to decide on what to automate and how and can be summed up as follows:

❍ give back to the Pilot his traditional task of flight path control and general flight management,

❍ arrange the flow of information to match the needs of the pilot,

❍ automate tasks for which human beings are ill-fitted,

❍ ensure that workload is not increased when operating back-up modes,

❍ make the transfer between automatic and manual flight management easy.

The way in which these criteria have been incorporated in the A320, and subsequently the A330/A340, shows that the flight deck is not just a collection of automatic devices into which the two pilots have been squeezed as an afterthought; it has been conceived around the pilot, with his needs as the central requirement. It is also not a revolutionary concept. It is a continuation of the logic and the ideas first incorporated into the design of the two crew A300.

SYSTEMS

The aim is to give the pilot only the same level of involvement as on a classic aircraft, on which he was accompanied by a Flight Engineer, to whom he gave general instructions for the management of the systems. The pilot never became involved in using controls to move valves - that was done by the Flight Engineer. We have not re-allocated those tasks to the pilot. On the A320, the tasks previously done by the Flight Engineer are done automatically, and the pilot gives his instructions to his "automatic engineer" via the overhead panel:

❍ the pilot selects the system state and the level of comfort,

❍ the pilot is informed of the system state and is alerted to failures and changes in status on the Electronic Centralised Aircraft Monitor (ECAM) (see Figure 1). A system diagram is automatically presented in the event of a failure (see Figure 2),

❍ systems automation is continued to reversionary modes: workload is not increased by loss of a primary system,

❍ the most appropriate systems information for the flight phase is presented automatically,

❍ the pilot can obtain a full report of systems performance and the relevant parameters any time he desires,

❍ system faults are recorded automatically.

NAVIGATION

The aim is again to give the pilot only the same level of involvement as on a classic

Figure 1

ECAM warning display

AUTO FLT RUD TRV LIM SYS
CAB PR SYS 1+2 FAULT
-MAN V/S CTL....AS RQRD

Figure 2

ECAM system display

aircraft, on which he was accompanied by a navigator. Instead of giving verbal instructions he now talks to his "automatic navigator" through the Multifunction Control and Display Unit (MCDU) (Figure 3). He can also intervene rapidly to achieve a short-term tactical re-routing and still receive the sort of assistance that he used to get from his human navigator.

- The route programming is simple, with entry through a single source.
- The changes to the route are simple to make, with automatic tuning of relevant navigation aids.
- The automatics monitor navigation accuracy.
- Short-term intervention is available head-up with consistent logic: push to obtain managed control by the Flight Management Guidance System (FMGS), pull to select manually (See Figure 4).
- The pilot can easily override any automatic selection.
- Optimum profiles are available in manual or automatic flight.
- Wind, groundspeed, drift continuously displayed to the pilot.

AUTOMATIC MONITORING

While there is general agreement that man is not good at long-term monitoring of systems, early developments in automation tended to change his role to that of a monitor. One of our design aims was to relieve the human being of tasks for which he is ill-suited, and we have therefore tried to allocate as much monitoring as possible to the automatics.

- Systems are self-monitored. All failures, including parameters outside the normal range, are signalled to the pilot.
- Failures are presented in order of priority, which is related to their seriousness and not the chronological order in which they occur.
- Failures which occur during high work-load periods (such as take-off) and are not directly relevant to the activity in question, are inhibited until the workload reduces and the failure can be dealt with calmly.
- Systems status is displayed when a change to it occurs, or when the pilot asks for it.
- The pilot is reminded if certain actions have not been completed.

It is also an Airbus aim to reduce the pilots' reliance on memory, with the ultimate intention of producing a "paperless cockpit"; although the latter is still some way from reality. Airbus is however among the leaders in progress towards the "Electronic library":

○ emergency and abnormal drills are displayed on the ECAM in order of priority,
○ take-off and landing checklists appear on the ECAM,
○ limiting speeds are displayed on the Primary Flight Display (PFD),
○ engine limits appear on the ECAM,
○ minimum speeds, continually recalculated, are displayed on the PFD,
○ V_{REF} and V_{APP} are on the PFD,
○ N1 rating is displayed on the ECAM.

The "dark cockpit concept" means that with all lights out the systems are normal and serviceable.

OPTIMUM INFORMATION DISPLAY

The aim of any information display should be to show the pilot what he needs to know, when he needs to know it. The A320 displays evolved from those of the A310 and A300-600 and benefited from experience gained with those aircraft to minimise display interpretation workload.

The main points can be summarized as follows:

○ the EFIS display (PFD, ND and ECAM) can be changed to suit the phase of flight; i.e. adaptable to give simple, uncluttered displays,
○ autoflight modes are displayed on the PFD,
○ failure messages are displayed centrally, and the items disappear when actioned,
○ use of colour to better discriminate between items (EFIS, ECAM and MCDU),
○ sideslip display adapted to β target in event of engine failure (β target gives minimum drag to improve single engined performance - take-off and go around only),
○ speed trend vector shows the speed that will be attained in 10 seconds if acceleration remains constant,
○ audio height call-outs on approach to landing.

Figure 3

Multifunction Control and Display Unit (MCDU)

Figure 4

Flight Management Guidance System (FMGS)

Design evolution towards an optimum working environment

FLY-BY-WIRE

FBW is another means of helping the pilot regain his traditional task. It is not entirely new since Concorde has been flying for many years with an earlier and less sophisticated form of FBW. It offers significant technical advantages and facilitates the provision of an autoflight system which is fully capable throughout the flight envelope from lift off until the end of the landing role. The A320 system can be used for the entire flight, should the pilot wish to do so. But it also offers enormous advantages to the pilot who wishes to "hand-fly" in the traditional manner and manual flight is no longer a degraded mode of operation.

FBW offers the following benefits to the pilot:

- ***Flight controls***

❍ Flight characteristics adjusted to his needs, making piloting a pleasure,

❍ Flight envelope protection provided so that the pilot can use the full capability of his aircraft at all times, and is not caught out by a simple or momentary lapse of concentration.

- ***Engine controls***

❍ Electric signalling allows more accurate thrust control with carefree power setting: no overboosting.

SIDESTICK

The final benefit to the pilot is the sidestick. Hydraulic actuators had replaced the need for muscles many years ago, and now electric signalling has eliminated control circuit friction; thus the control stick can be any size that we want, and the flight deck no longer has to be arranged around a massive impediment - the conventional stick and yoke - but can be designed to be the optimum working environment.

The sidestick gives the following advantages:

❍ an unobstructed view of the flight instruments,

❍ provision of a stowable table directly in front of each pilot,

❍ provision of comfortable foot rests.

CONCLUSION

The A320 has been conceived about the needs of human beings - pilots, maintenance engineers, and passengers - using the experience gained with previous Airbus aircraft. It does not make the pilot redundant. It is an advanced technology aircraft and it is undoubtedly the most capable civil aircraft currently in service with regard to the extent of the automatic systems available to the pilot. But it is also an aircraft that is very easy to operate in the traditional manner. The A320 is of course still subject to the physical laws which govern all aircraft. It leaves the choice to the pilot and it cares about his needs. Not just by providing flight envelope protection, but also by doing routine tasks such as monitoring systems. It unloads the pilot so that he can concentrate on what is important. ■

by Nicholas Ruston, Technical Marketing Manager, Airbus Product Marketing

COMMONALITY

Airlines choose one aircraft instead of another primarily because of the net financial effect of performance capability, revenue-earning capability, and total operating costs. Commonality reduces operating costs by reducing aircrew-related costs and airframe and engine spares investments. Savings can be substantial : equivalent to a 10 % reduction in direct operating costs on the A320 family and equivalent to a 5 % reduction in direct operating costs on the A330/A340. These savings are "per additional aircraft" : that is the saving made by adding an Airbus with commonality instead of an alternative aircraft without commonality. Clearly, with savings of this magnitude, commonality can be a decisive factor in aircraft selection.

COMMON TYPE RATING AND CROSS CREW QUALIFICATION

The A319, A320, and A321 will have a Common Type Rating (as do the A300-600 and A310 already). Thus a pilot with an A320 Type Rating is qualified to fly the A319 and A321 without any further training.

The A330, A340, and A320 family will have Cross Crew Qualification. A pilot with an A330 Type Rating, for example, can become qualified to fly the A340 by doing the relevant Difference Training course (see Figure 1).

Whereas a full Type Rating course takes about 27 working days, Difference Training courses range from 3 days (A330 to A340) to 10 days (A320 to A340). Thus Cross Crew Qualification enables pilots to fly two, or more, closely-related aircraft continually.

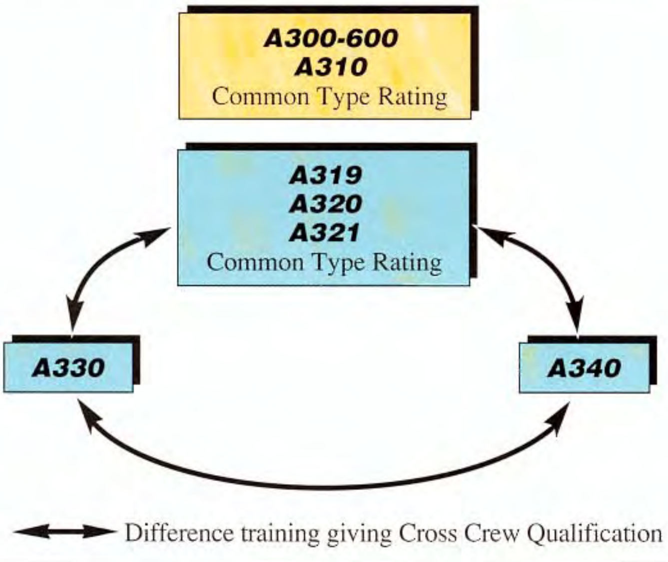
Common Type Rating and Cross Crew Qualification both enable one pool of pilots to fly two, or more, different aircraft types continually.

The requirements for Cross Crew Qualification are set out in the FAA Crew Qualification Requirements AC 120-53. The commonality across the A330, A340, A320 family is such that handling characteristics are virtually identical, cockpits almost identical, and systems very similar. Normal and emergency procedures are also identical or very similar.

Common Type Rating and Cross Crew Qualification give aircrew mobility that is unique to Airbus Industrie. The economic repercussions are far-reaching: shorter and less costly training, improved aircrew productivity because non-productive time is reduced, and simulator economies because less simulator time is required.

Figure 1

Aircrew mobility in the Airbus family



"UP FRONT" AND "STEADY STATE" SAVINGS

Commonality savings fall naturally under two headings : "up front" and "steady state".

Up front savings are reductions in the capital investments that must be made on the entry into service of an additional aircraft type. Under this heading come :

- ***Entry into service crew training savings:*** fewer additional crews need to be trained, because improvements in aircrew productivity reduce total crew number..
- ***Simulator economies:*** fewer crews, needing less training, mean that simulator requirements are substantially reduced. In some cases no simulator investment whatever is needed.
- ***Airframe spares investment savings:*** spares commonality in value terms A330/A340 is about 80% and A319/A320/A321 is about 90%, meaning that less capital needs to be tied up in spares stocks.
- ***Engine spares investment savings:*** in the A320 family engine differences can be FADEC (Full Authority Digital Engine Control) only, giving total spares commonality and very substantial investment economies.

All "up front" savings are money which does not need to be spent when adding one family member to another. It is useful to annualise these savings and this can be done by considering them as money which can be invested to yield, say 10% per year.

Steady state savings are those annual savings which are realised during the operational life of the aircraft after the initial entry into service period is over. Under this heading come:

- *Aircrew training savings:* fewer crews, needing less training, which is substantially shorter and cheaper.
- *Aircrew productivity savings:* fewer crews are required for a given number of flying hours, reducing aircrew costs.

In addition to the above there are savings that are more difficult to estimate accurately, such as:

- *Maintenance Engineering savings:*
  - ○ On direct productive manhours, "Learning curve" benefits on maintenance labour costs. Adding another A320 version, for example, is not the same as adding a totally new aircraft type: the new version will enter service at the same point on the "learning curve" as the existing A320 fleet. This effectively removes the 20-25% "bump" in airframe and engine maintenance labour costs that "Aircraft X" would be subject to on entry into service.
  - ○ On indirect maintenance costs: *Engineering* - one specialist can cover both models; *Planning* - the same philosophy applies to both models and so tasks are similar; *Technical Publications* - familiarity with documents and their use; *Ground Support Equipment* - much is common or easily adapted for additional wide or narrow body models.
  - ○ On subcontracted maintenance, the effect of scale should lead to economies in negotiating contracts.
- *Aircrew administration savings:* it has been estimated that the administrative savings on one pool of pilots instead of two is worth about $20,000 per aircraft per year.

A319/A320/A321

Commonality savings are essentially comparative: "without commonality" versus "with commonality".

Let us consider the alternative of adding 15 Aircraft X or 15 A321 to an existing fleet of 15 A320.

Common Type Rating

In the A320 + Aircraft X case, pilots Type Rated on the A320 would fly them for, say, two years. They would then do Aircraft X Type Ratings and fly this aircraft for two years. Thus in four years they would do two Type Ratings.

In the A320 + A321 case, pilots Type Rated on the A320 would then fly the A320 and A321 for a four year period. Thus in four years they would do only one Type Rating instead of two.

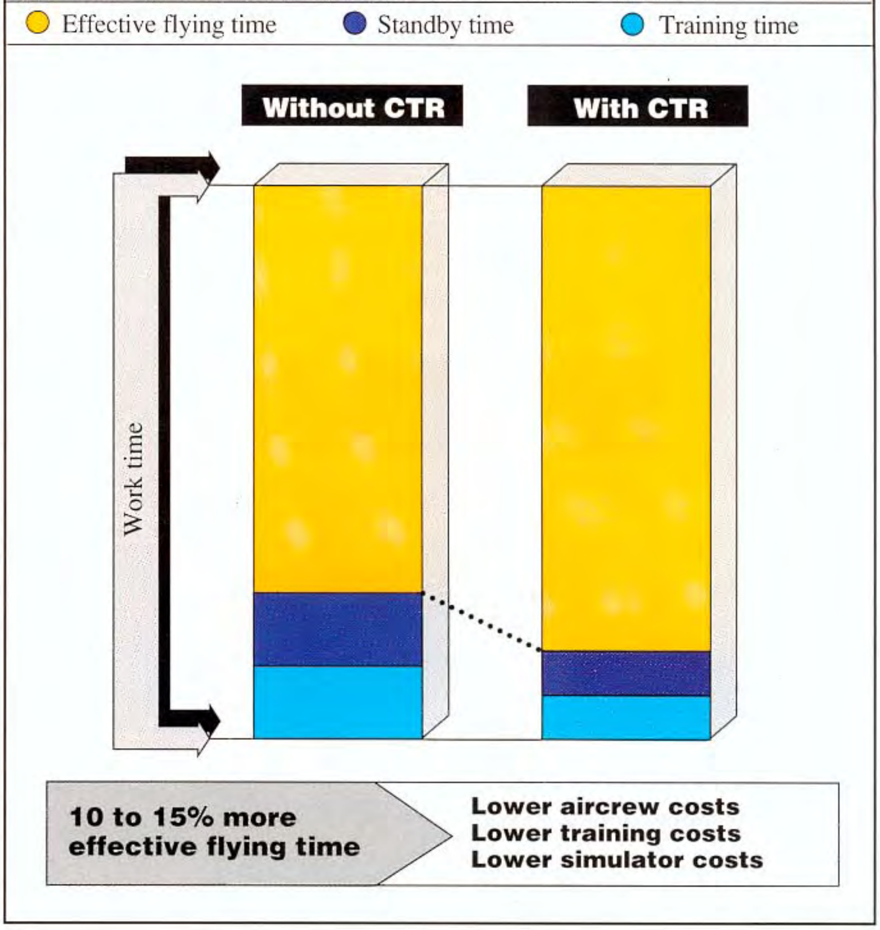
Aircrew non-productive time is made up of training (Type Rating and Recurrent) and stand-by duty. As we have seen above, in the A320 + A321 case, Type Rating time per crew is effectively halved. Thus the reduction in annual simulator time is substantial. Recurrent training, being a statutory requirement, is little affected and typically occupies about six days per year.

Stand-by duty is an important part of a pilot's duties. At their hubs airlines typically have one stand-by crew available for up to eight departures of each aircraft type. Thus in the A320 + Aircraft X case, four A320 departures and four Aircraft X departures would each require a stand-by crew. In the equivalent A320 + A321 case one stand-by crew could cover the four A320 and four A321 departures. Thus in this case only half the number of stand-by crews would be required.

The overall effect of this is to increase the effective flying time of crews with a Common Type Rating by 10-15% (Figure 2). This improvement in productivity enables the number of crews per aircraft in a fleet to be reduced proportionately.

Figure 2

Common Type Rating (CTR) - Aircrew



Thus Common Type Rating gives savings in three separate but inter-dependent ways: fewer crews, who require less training, which in turn requires less simulator investment.

- *Entry into service crew training*
  - ○ On the introduction of 15 Aircraft X a new pool of Aircraft X pilots must be created. Assuming a typical 5.5 crews per aircraft, the training requirement will be Type Ratings for 83 crews.

○ On the introduction of 15 A321 the situation is radically different : existing A320 crews are already qualified to fly the new aircraft. Instead of the creation of a new pool of pilots the requirement is simply an increase in the size of the existing pool of pilots. Fewer new crews are required because of the aircrew productivity improvements stemming from Common Type Rating. Instead of a typical 5.5 crews per aircraft, the crewing requirement is 4.9 crews per aircraft (assuming a productivity improvement of 12.5%). The entry into service training requirement is Type Ratings for 64 crews instead of 83 crews, a reduction of 19 crews.

- ***Simulator economies***

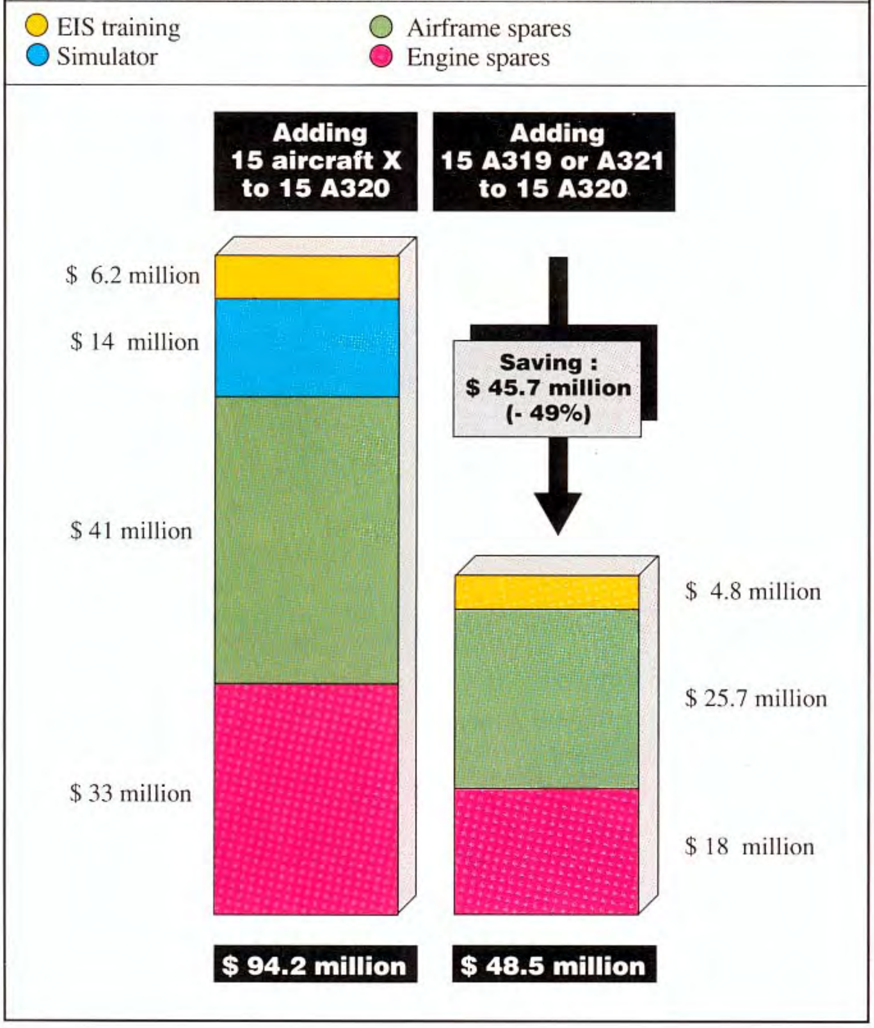
○ One Full Flight Simulator (FFS) is required for the base fleet of 15 A320. Simulator utilisation is about 65% of capacity.

○ On the introduction of 15 Aircraft X a new FFS will be required costing about $14,000,000, the utilisation of which will also be about 65%.

○ On the introduction of 15 A321 no simulator investment whatever will be required because the existing A320 FFS has enough spare capacity to cover the increased Recurrent Training requirements of the expanded fleet. FFS utilisation will increase from about 65% to about 80% of capacity.

Figure 3

Additional investment on adding 15 aircraft to 15 A320 base fleet



- ***Airframe spares investment savings***

○ The introduction of 15 Aircraft X requires investment in spares which have no commonality with existing A320 spares.

○ The introduction of 15 A321 requires a much lower additional investment because A319, A320, A321 spares are 90% common by value. The effect of this is to reduce total spares investment by about 19%. About 88% of the total investment will be common A320/A321, two tranches of about 6% being specific to type.

- ***Engine spares investment savings***

○ The introduction of 15 Aircraft X requires investment in engine spares with no commonality with existing A320 spares.

○ The introduction of 15 A321 with FADEC-only engine differences results in substantial savings because engine spares are totally common. In this case the total engine spares investment is of the order of 23 % less.

Figure 3 shows the additional "up front" investment required on adding 15 Aircraft X or 15 A321 to an existing fleet of 15 A320. While these figures are approximate they do illustrate the order of magnitude of the savings involved: about $3,000,000 less per aircraft.

- ***Aircrew training savings***

○ On the introduction of 15 Aircraft X annual training costs will double, there being two distinct fleets of 15 Aircraft each.

○ On introduction of the A321 annual training costs increase by only about 19% because Type Rating training remains unchanged, while Recurrent Training more than doubles. This substantial saving (generally $200,000 - $250,000 per additional aircraft per year) is made throughout the service life of the fleet, after the entry into service period is over.

- ***Aircrew productivity savings***

○ On the introduction of 15 Aircraft X crew numbers, and therefore crew costs, will double.

○ On the introduction of 15 A321, because of aircrew productivity improvements due to reduced non-productive time, aircrew numbers will increase by 64 instead of 83, a saving of 19 crews (11.5%). This saving, which approaches $300,000 per additional aircraft per year is made throughout the service life of the fleet.

If "up front" savings are annualised, by treating them as money which need not be spent and can therefore be invested to yield 10% per year, "steady state" and "up front" savings can be combined to show an annual savings of about $800,000 per additional A321 per year (see Figure 4a). This saving will not change significantly whether the additional aircraft are A319 or A321; the annual savings are of about 10% of annual direct operating cost. No airline can ignore savings of this size.

A330/A340

Commonality savings on the A330 and A340 come about in exactly the same way as on the A319, A320, A321 but there are certain differences which need to be appreciated.

The major savings areas are aircrew-related, as before, but crew costs form a smaller percentage of direct operating costs on large long range aircraft than they do on smaller short range aircraft, although there are more crews per aircraft. Thus savings are a smaller percentage of annual direct operating costs.

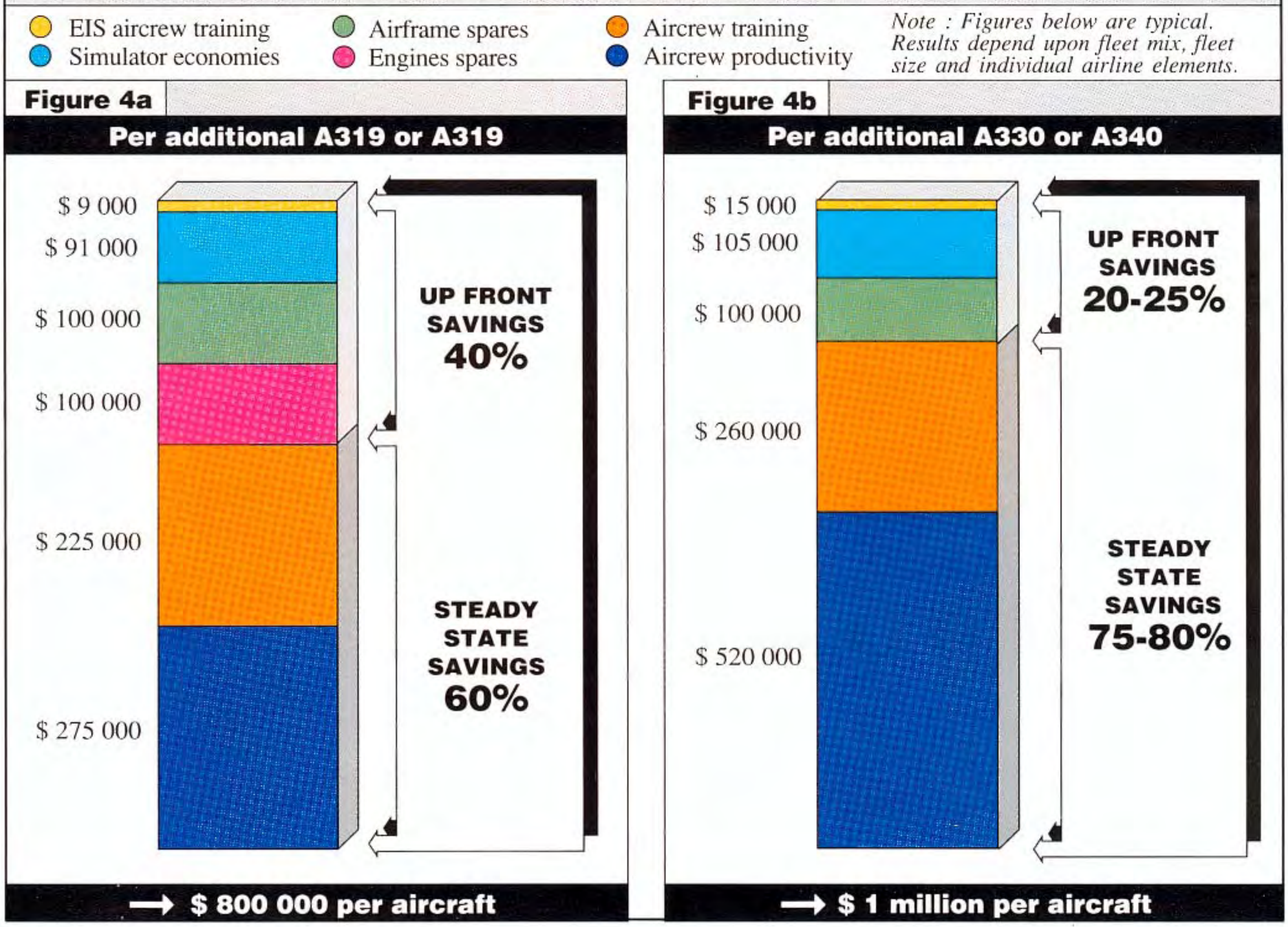
Entry into service aircrew training savings, simulator economies, and airframe spares investment savings are generally similar to those with the A320 family, in dollar terms.

There is no engine commonality between the A330 and A340, so this element is missing.

Aircrew training and aircrew productivity savings are significantly greater because crew numbers and training costs are higher.

Figure 4b shows the order of magnitude of the annual commonality savings that can be made adding the A330 to an existing A340 fleet or vice versa. Savings in the region of $1,000,000 per aircraft per year can be made, which is equivalent to a reduction in annual direct operating costs of about 5%.

Total commonality savings - Approximate annual savings per additional aircraft



SUMMARY

Commonality can do more to reduce operating costs in mixed fleets than any technological factors

The commonality savings on A320-family fleets is equivalent to a reduction in fuel burn of about 40% for additional aircraft or a reduction of about 20% for a whole fleet. Thus any alternative aircraft to the A319 or A321 as an addition to an A320 fleet must demonstrate a fuel burn advantage of at least 40% in order to be competitive. No aircraft can do this.

The commonality savings on A330/A340 fleets is equivalent to a reduction in fuel burn of 15-20% for additional aircraft, or a reduction of 7.5-10% for a whole fleet. Thus any alternative aircraft as an addition to an A330 or A340 fleet must demonstrate a fuel burn advantage of at least 15-20% in order to be competitive. No such aircraft exists.

Over the past five years, the combined efforts of engine and aircraft manufacturers have not achieved improvements in fuel burn equivalent to commonality savings. ❑

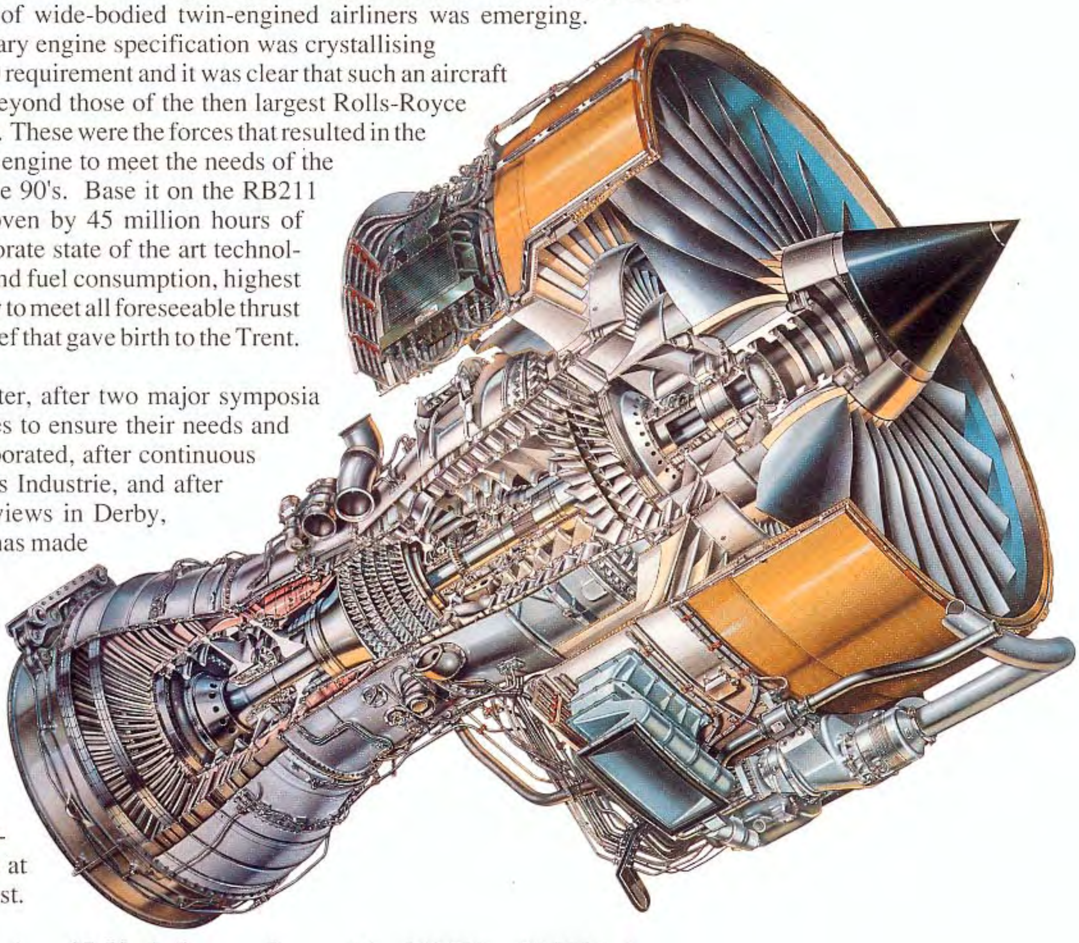
TRENT

RELIABILITY BY DESIGN

by John Cundy Head of Propulsion Systems and Tony Gale Chief Design Engineer - Trent ROLLS-ROYCE

By early 1987 it was apparent that, with the combination of continuing growth, congestion and the need to replace the first generation of wide-bodies, a new generation of wide-bodied twin-engined airliners was emerging. The necessary engine specification was crystallising around the Airbus A330 requirement and it was clear that such an aircraft would require thrusts beyond those of the then largest Rolls-Royce engine - the RB211-524. These were the forces that resulted in the brief : "Design the best engine to meet the needs of the new Wide Bodies of the 90's. Base it on the RB211 three-shaft concept proven by 45 million hours of experience, and incorporate state of the art technology for lowest weight and fuel consumption, highest reliability and capability to meet all foreseeable thrust needs". This was the brief that gave birth to the Trent.

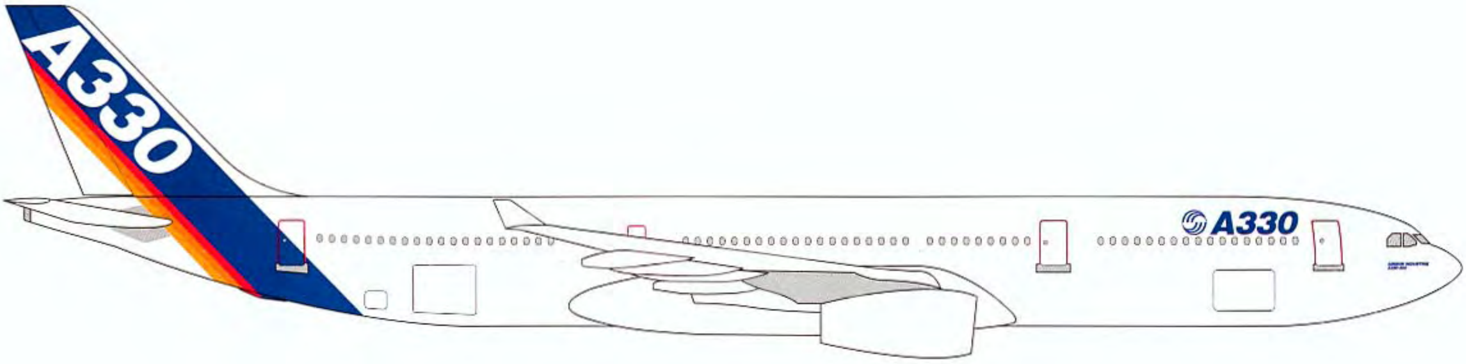
Now, five years later, after two major symposia with the world's airlines to ensure their needs and knowledge were incorporated, after continuous discussions with Airbus Industrie, and after numerous technical reviews in Derby, the Engineering Team has made its decisions and the Trent is a reality. Since the first demonstrator ran in August 1990, six heavily instrumented engines have accumulated over 700 hours of testing, providing data to verify the design calculations, and have run at up to 80,000 lbs of thrust.



The Trent 700, featuring a 97.5 inch diameter fan capable of 69,000 to 78,000 lb thrust, is to be initially certificated at 72,000 lb thrust and will enter service in January 1995 on the A330.

A330s powered by the Trent have been ordered by Trans World Airlines, Cathay Pacific, Garuda and ILFC.

Before finalising the design philosophy for the engine, a considerable amount of time and effort was taken to ensure that the product would have a sustainable competitive advantage in a demanding market. The chosen strategy for the Trent was one of providing an engine with the best overall operating economics. Let us now explore the rationale for this before examining some of the more technical design aspects.



PRODUCT STRATEGY

In an increasingly deregulated and competitive environment where "bottom-line" financial results become the management priority, delivering an aircraft/engine combination that maximises revenues and minimises costs is an imperative. For the A330 engine therefore, Rolls-Royce's first task was to ensure that a by-pass ratio was chosen which optimised a blend of weight, fuel consumption and drag to provide the best payload and range - hence delivering the highest revenues. Other important operational issues such as thrust to reduce the time taken to climb to a cruise altitude were also considered. The 5:1 by-pass ratio of the Trent 700 and the large thrust capability of the Trent address these requirements admirably.

✦ *Trent uses the best proven advanced technology from the RB211 family.*
✦ *Current RB211s are the most reliable in service.*
✦ *Trent will achieve third generation reliability.*

Proven technology for Trent reliability

Turning to the cost side of the equation, an analysis of aircraft operating economics shows that whilst fuel comprises around 22% of Direct Operating Cost (DOC), the differences between competing engines - across a broad range of aircraft - is slight, varying from zero to a maximum of 4%. Engine maintenance costs, on the other hand, making up around 5% of DOC, display wide differences between engines, with the costs of some of the more unreliable products reaching double those of their reliable competitors.

Reliability is a function of operating temperatures and materials and cooling technology. Here again bypass ratio (BPR) is an important factor. A modest increase in BPR - one that permits the use of a relatively large core running relatively cool and using proven technology - will enable both efficiency gains and low core temperatures and hence high reliability.

The Trent 700 was, therefore, designed to this philosophy. It is effectively a larger version of the RB211-535 engine, blending the proven three-shaft RB211 concept with other advanced technology such as FADEC, single-crystal turbine blades and a low-emissions combustor to produce an efficient engine with unsurpassed reliability - the key to best economics.

RELIABILITY AND ETOPS

Ensuring that the lessons of experience have been addressed in the design is a major route to enhanced reliability. These have been captured in the Rolls-Royce Product Support Wish List, which embodies the RB211 Operators' experience.

All designs are checked by a Reliability Committee to ensure that all historical causes of in-flight shut-downs (IFSD) and delays/cancellations have been addressed and that any areas of doubt are "over-checked" by early rigorous testing.

Particular attention has been paid to the performance of accessories which contribute to a large proportion of IFSD, Delays and Cancellations and Aborts.

WIDE CHORD FAN BLADE

A key feature in the success of the Trent is its advanced wide chord fan. Rolls-Royce experience of wide chord fans stretches back to the 1970s.

The advanced design of the fan blade for the Trent involves diffusion bonding and superplastic forming in the manufacturing process to provide outstanding performance allied to strength, low weight and resistance to bird strikes.

A wide chord blade does not require reinforcing snubbers which are used to stabilise the narrow-chord fan blades, and can result in a reduction in aerodynamic performance and a consequent penalty in fuel consumption. Rolls-Royce produces its wide chord fans with a smaller number of wider and stiffer blades.

In the seven years since October 1984 when Rolls-Royce wide chord fan blades entered service on the RB211-535E4 engine, the design has been applied to all of the Rolls-Royce civil production turbofans, the Tay, the five-nation V2500, the RB211-524G/H and the Trent.

To each, the design has brought the benefits of reduced fuel consumption, enhanced resistance to foreign object damage and significant noise reduction.

Rolls-Royce pioneered wide-chord fan technology with which it has a ten-year lead in operating experience.

Early in the design process a special task force was established to forestall problems in this area.

Extended Range Twin-Engined Operations (ETOPS) is a fundamental customer requirement to maximise the operational flexibility of new twin-engined wide-bodies.

The Trent is designed for a reliability level of better than 0.013 in IFSD per 1000 flight hours (ie. 1 shutdown every 80,000 hours) at entry into service. This level of reliability provides the opportunity to secure approval for the maximum diversion time of 180 minutes.

Reliability testing is further enhanced by a dedicated engine which is to be built and operated as closely as possible to airline operation for 3000 cycles, including a number of simulated 180-minute diversions.

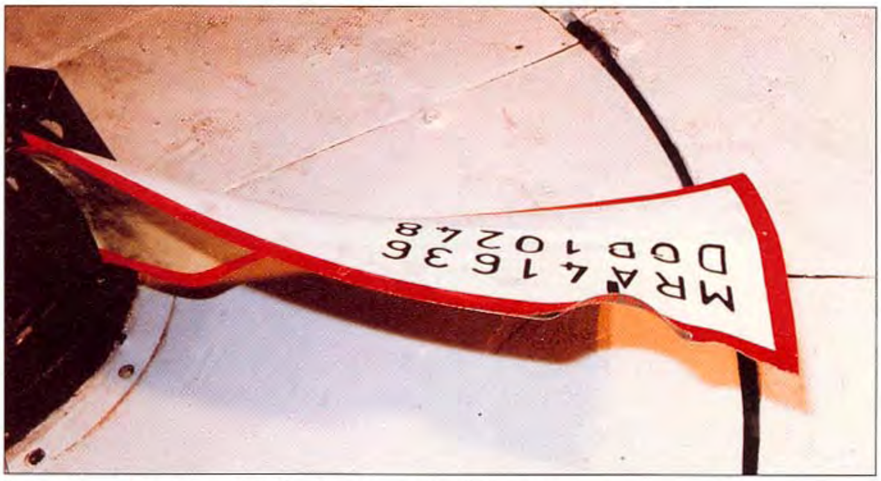
The above total quality approach is planned to simulate the equivalent of two years of service experience prior to entry into service and is the basis of the plan for application for early ETOPS.

THREE SHAFT DESIGN

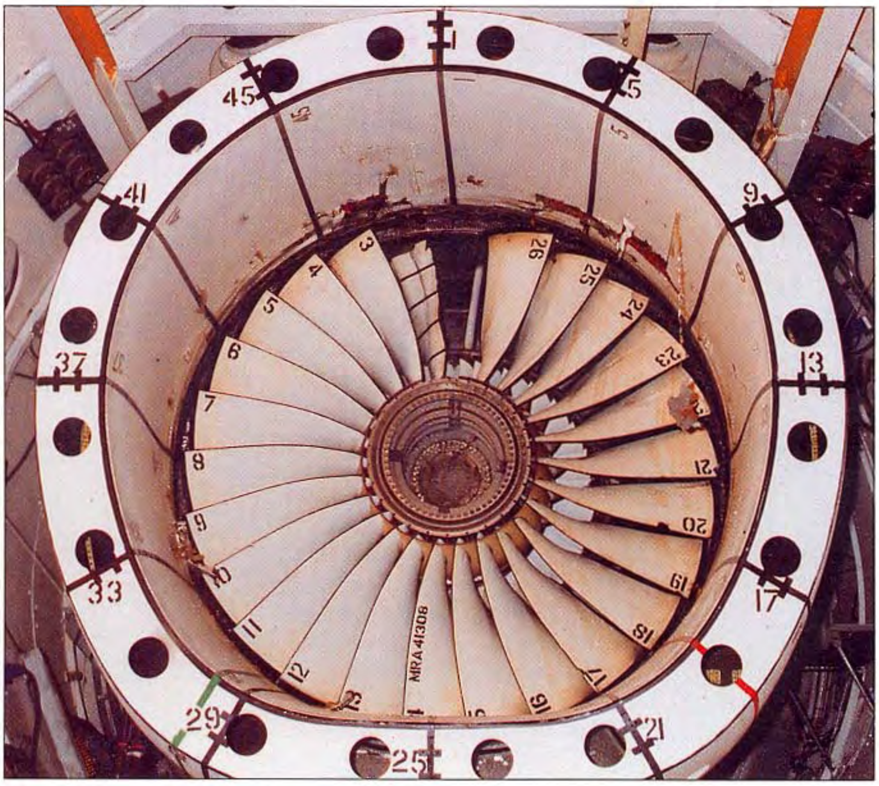
Reliability is not the only virtue bestowed by the unique three-shaft design of the RB211. It provides other fundamental advantages.

A high-bypass turbofan has a high-pressure core which creates gas horsepower, and a low pressure system which converts this into thrust. On the three-shaft engine the fan is driven by its own turbine and can therefore run at its optimum speed. The high-pressure core has two compressors, Intermediate-Pressure (IP) and High-Pressure (HP), each driven by its own single stage Turbine. The IP and HP compressors are on separate shafts and each rotates at optimum speed, enabling them to operate at peak efficiency with the minimum number of compressor and turbine stages. This results in a shorter and more rigid engine than a two-shaft design. The rigidity of the engine structure plus careful control of blade-tip clearances combine to make the RB211 a world leader in low deterioration, with a typical benefit of 2% fuel burn and the associated reduction in hot end distress towards the end of a service life.

The three-shaft concept offers unparallelled growth flexibility as demonstrated by the current RB211 family which spans 40 to 60,000 lbs thrust. This range will be extended to over 90,000 lbs with today's enhanced technology Trent core and to over 100,000 lbs with further improvements currently being demonstrated in Advanced Engineering Programmes. The three-shaft concept yields further benefits at the larger engine size



Example of a damaged blade after a bird impact



Trent fan containment system after blade off test

and Rolls-Royce is confident that the Trent will be the lightest engine for the new big twins.

DESIGN VERIFICATION TESTING

Design verification testing is now well advanced. Testing has included simulated altitude performance work at the Pyestock High Altitude Facility. Measurements of cruise performance, handling and relighting at different flight speeds and temperatures at altitudes ranging from 10,000 feet to 42,000 feet have confirmed pretest predictions.

An engine has been "bent" by hydraulic rams to simulate the intake bending loads at take-off rotation. Predicted carcase deflections have been verified and excellent core surge margin demonstrated by fuel "spiking" tests.

On schedule, the first Trent 700 certification engine delivered an ideal thrust of 80,000 lb, well in excess of that needed to power the A330.

Aerodynamic rig tests have demonstrated or exceeded the aerodynamic design goals on the Fan, IP compressor, HP compressor, HP turbine and LP turbine. The Rolls-Royce Cray Supercomputer has played a significant part in defining advances in component performance as exemplified by the success on the HP compressor which demonstrated 92% polytropic efficiency, near to the practical limit.

The benefit of three dimensioned aerodynamic analysis were also underlined by the first run of the full size, all new, LP turbine which exceeded the predicted performance.

Rig and engine testing of the new combustor has demonstrated a 30% reduction in oxides of nitrogen (NOx) while maintaining low levels of other emissions such as hydrocarbons.

Mechanical rig testing is progressing to plan with some notable successes on Fan Integrity.

FAN INTEGRITY

Rolls-Royce is proud of its record on fan blades. In 40 million hours of operation to date, there has never been a Fan Blade failure on an RB211 engine.

The Trent second generation Wide Chord Fan Blades have successfully demonstrated strikes from 2.5 lb flocking birds and 8 lb single birds, and ingestion tests on the Engine Core have been equally successful.

The strategy to design the fan and core blades beyond current legislation was deliberate to anticipate future requirements and ensure that the immaculate record of no failures in 5 million hours of service operation on the first generation of Wide Chord Fan is repeated on the Trent.

The capability of the Rolls-Royce Wide Chord Fan was well demonstrated by a service event in Chicago where a 535E4 ingested at least three 8 lb Canada Geese, on aircraft take-off, and was able to keep running and provide power during the go-round.

Evolutionary development of the RB211-535 Aluminium Kevlar Fan Containment System has paid off with a successful rig test at Trent size.

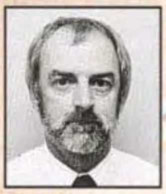
The excellent condition of the parts following the violent event of the Fan Blade Off Rig Test is evident in the post test photograph, and leads to a high confidence of success in the formal Engine Certification Blade Off Demonstration and hence the prediction of production engine weight.

SUMMARY

The Rolls-Royce commitment to the success of the Trent - the first Rolls-Royce engine to power an Airbus aircraft - is total. With power and performance to match all that the A330 requires and with reliability and efficiency levels focused on minimising operating costs, Trent development is well on course to start flight test on the A330 early in 1994. Its design, blending state-of-the-art technology with a unique and proven concept is aimed at setting the standard for the new generation of large high bypass-ratio civil turbofans. Progress to date provides every confidence that this vision will become a reality. ■

AGEING

THE ELECTRICAL CONNECTION



by Colin Kane
Engineer Electrical Systems
Airbus Product Support

One thing that human beings and aircraft fleets have in common is that their average age is rising. As costs have increased and recession has become more widespread, airlines are tending to keep their older aircraft rather than buy this year's model.

The other thing they have in common is the tendency for bits and pieces to need more attention the older they get ! This, in aircraft, is as true for the electrical wire installation as for the airframe itself.

After years in service this clamp has slipped down the tapered strut and the harness is not held securely.

Structural surveys resulting in airframe life extension programmes are not new, but very little information is available on the effects of ageing for wiring installations. Airbus aircraft have a design goal of twenty years service. By the end of the century there will be over one hundred Airbus aircraft exceeding this figure and with little chance of being retired. Maintenance support for senior citizens and newly arrived babies is equally important to Airbus Industrie and so, the Electrical Systems department of Product Support has launched the Ageing Aircraft Electrical Installation Survey programme.

THE AIMS

In general, the idea is to learn more about how the whole package - wire, conduits, connectors, clamps, supports and so on - stand up to the effects of years of use.

The information gleaned from the survey will be available for use in various ways:

○ ***for existing aircraft****:* to create or revise maintenance procedures for inclusion in existing manuals with regard to ageing wire installations and to collate the information to make improvements to existing installations either in production or by Service Bulletin action;

○ ***for future projects****:* review the design criteria in the light of the findings;

○ ***for airlines****:* respond to support problems from a more knowledgeable and informed viewpoint;

○ ***for sales****:* accurate predictions of expected life and reliability figures.

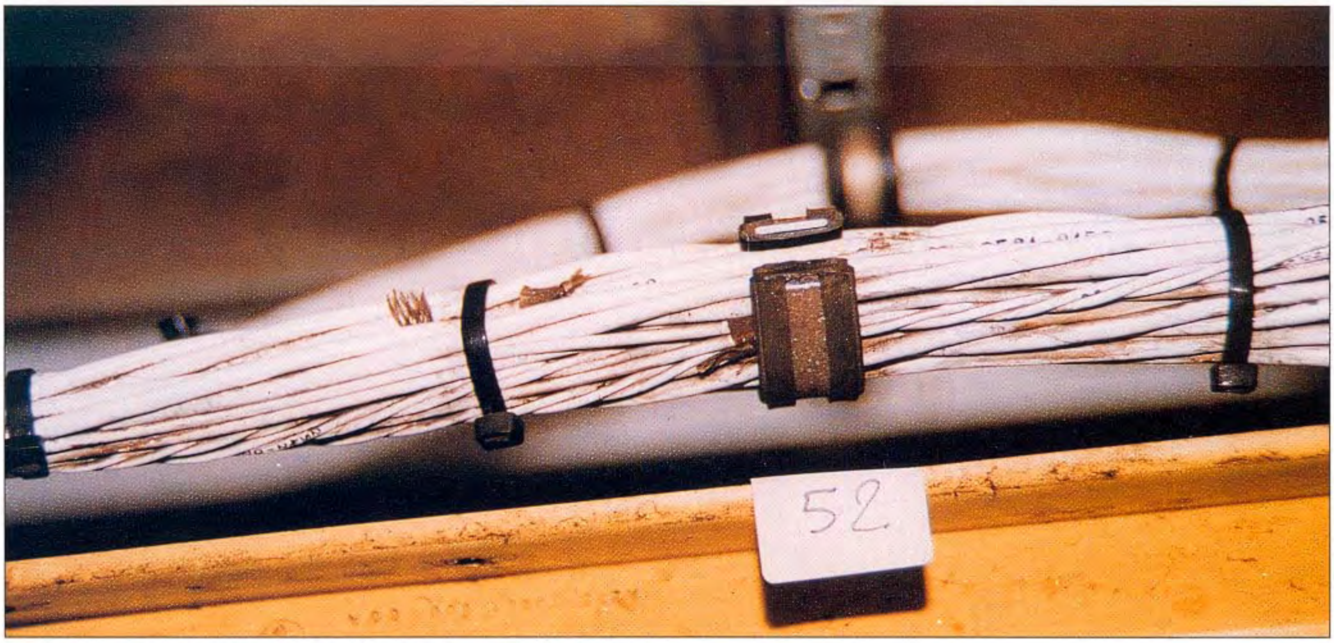
METHODS

Inspections will be carried out on a number of aircraft of advanced years and high flight hours and/or cycles during their "D" checks. A team of Airbus engineers will carry out a physical and detailed visual inspection of the complete electrical installation. In preference this will be done at the home maintenance base of the various airlines selected, thus reflecting the climatic conditions of service and operational differences.

The team will be comprised of four to six inspectors and each inspection is expected to take no more than seven working days if access is not restricted.

The findings from each inspection will not be disclosed outside Airbus except to the host airline for their own analysis.

The tape wrap has slipped out of this clamp allowing the harness to spread and deform.



This clamp has sheered right off and the harness is now unsupported.

When

In actual fact the surveys have already started. The first was carried out in March 1992 on four separate aircraft. It was successful and a lot of interesting data was accumulated. The second was carried out in October and at the time of writing the data obtained is being analysed and collated for study and comparison.

The search has begun for host airlines with aircraft available and suitable for the continuation of the survey.

So far

So far so good. Airbus was very pleased with the overall condition of the wire installation on the aircraft examined. One or two areas, where trouble was expected, were confirmed. As these were areas where operators had identified areas requiring improvements, design solutions were already in hand, for which the requirement was further confirmed.

Some areas are more prone to wear and tear as the years go by, mainly swamp, flex and vibration areas, undercarriage bays, hydraulic bays, wing trailing edge, pylons etc. and in these areas some ageing effects were found. The complete series of inspections will need to be finished before a full evaluation of the findings and recommendations for hardening these areas can be completed.

Choices

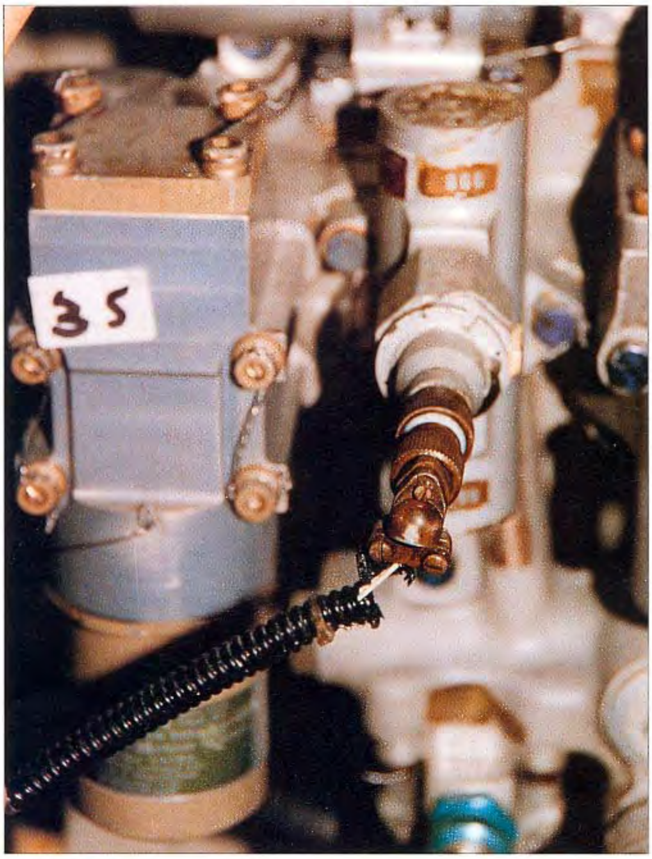
The advance of wire insulation technology in the sixties gave rise to lightweight, small diameter wires with excellent electrical properties and good mechanical resistance to aggression. In service one or two drawbacks became evident and airframe manufactures had some hard decisions to make regarding choice of wire in specific zones and for defined applications.

The review of wiring installation on Airbus aircraft is also intended to confirm the selection of wire types and our initial findings have been very encouraging in this respect.

And now

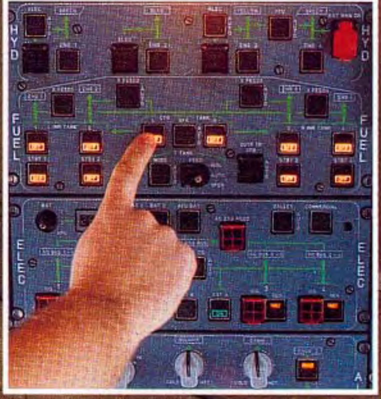
The inspections will continue until the end of 1994, minutely, critically and open-mindedly until as much as possible has been learned about how aircraft wiring will age. With this knowledge Airbus can help ensure a reliable and relatively trouble free electrical installation for the full service life of its aircraft. ■

Deterioration of convoluted duct at a connector backshell - the protection for the wires is incomplete.



by Colin Orme
Fuel Systems Engineer
Airbus Engineering

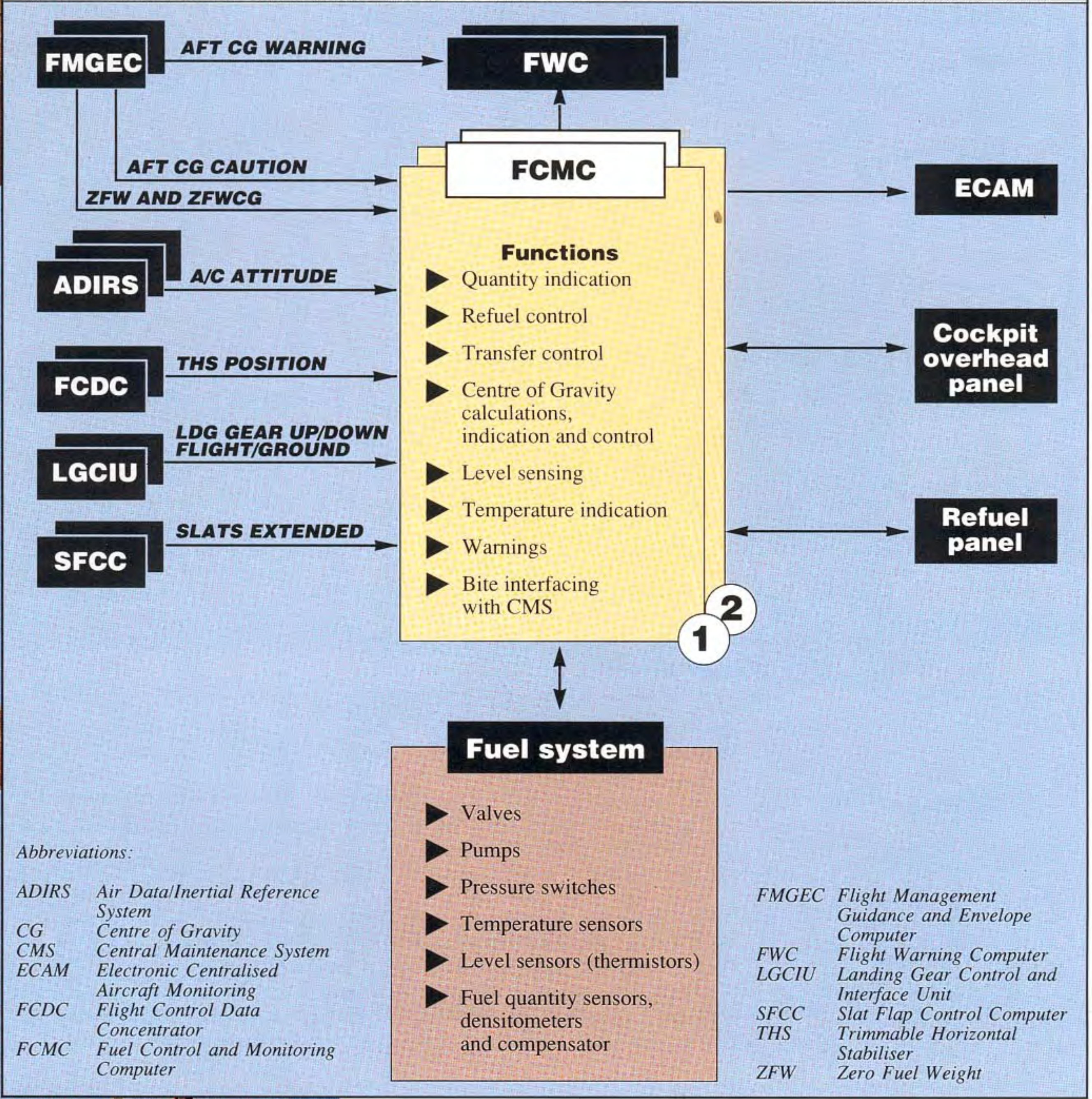
FUEL
A330/A340



The fuel systems on A330 and A340 aircraft possess a high degree of commonality. This stems from the near identical wings and identical horizontal stabilisers (trim tank) which are used for fuel storage. On the A340, the wing centre section is also used. Additionally, trim tank fuel is used to maintain an optimum rearward centre of gravity (CG) in cruise. This reduces drag, giving enhanced aircraft performance. For these reasons, the fuel system configurations in the A330 and A340 are very similar and much of the equipment is interchangeable, including pumps, valves, fuel quantity sensors, fuel level sensors and the computers. Overall control of the fuel system, except engine feed, is through two identical Fuel Control and Monitoring Computers (FCMCs) (see Figure 1). The FCMCs are pin-programmed appropriately to cater for two engines and five fuel tanks for the A330, and four engines and six fuel tanks for the A340. Detailed aspects of the overall system and the various FCMC functions are treated in the following descriptions.

Figure 1

Fuel Control and Monitoring Computers - Interface with aircraft



Abbreviations:

ADIRS	*Air Data/Inertial Reference System*
CG	*Centre of Gravity*
CMS	*Central Maintenance System*
ECAM	*Electronic Centralised Aircraft Monitoring*
FCDC	*Flight Control Data Concentrator*
FCMC	*Fuel Control and Monitoring Computer*
FMGEC	*Flight Management Guidance and Envelope Computer*
FWC	*Flight Warning Computer*
LGCIU	*Landing Gear Control and Interface Unit*
SFCC	*Slat Flap Control Computer*
THS	*Trimmable Horizontal Stabiliser*
ZFW	*Zero Fuel Weight*

THE TANKS

All internal surfaces are treated with proven anti-corrosion materials. Water accumulation is discouraged by the nature of the engine feed system, where only the collector cells feed the engines. All other tanks are transfer tanks. Figure 2 shows engine feed system, and Figure 3 gives tank capacities.

Collector cell contents are permanently agitated and replenished, resulting in the dispersion of any water that may be present. This feature complements the drain valves located at the low points in each tank.

The trim tank is equipped with a dedicated water scavenge system. This responds to the variable nature of the centre of gravity control function.

VENTILATION

Individual tank ventilation is through normally dry compartments (vent tanks) located at each wing tip and in the right tip of the horizontal stabiliser. These compartments interface with the atmosphere through NACA vents and flame arrestors.

Over and under pressure protection is achieved by pipe sizing and suitably positioned relief devices.

Figure 2

A330/A340 Overall plumbing configuration

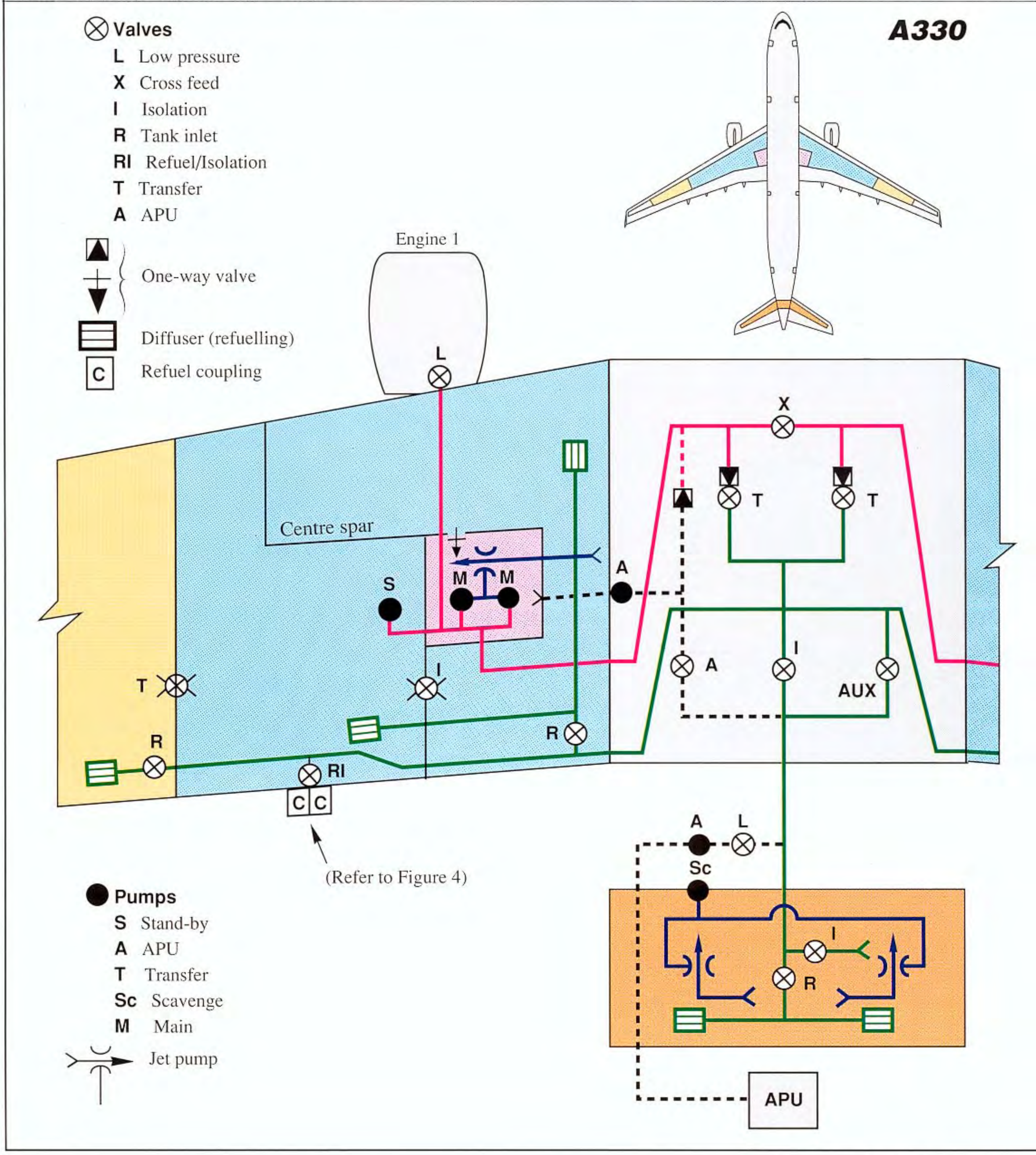
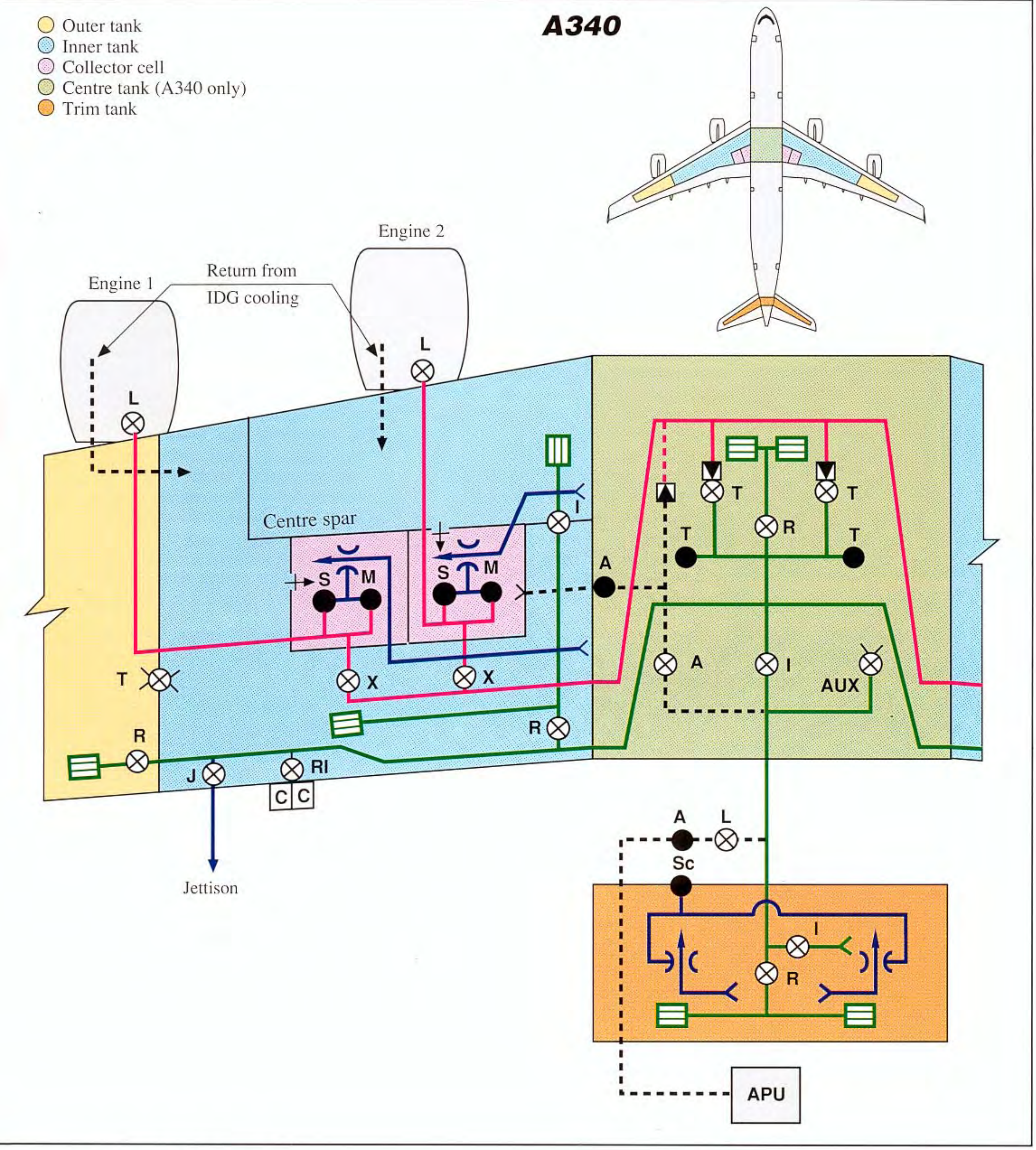


Figure 3

Usable fuel (values rounded) (fuel density 0.785 kg/l - 6.551 lb/US gal)

	A330				**A340**				
	Outer	Inner	Trim	Total	Outer	Inner	Centre	Trim	Total
Volume									
Litres	3,624 x 2	41,904 x 2	6,114	97,170	3,624 x 2	41,904 x 2	41,468	6,114	138,638
US Gal.	957 x 2	11,070 x 2	1,615	25,670	957 x 2	11,070 x 2	10,955	1,615	36,624
Weight									
Kg	2 845 x 2	32,895 x 2	4,799	76,78	2 845 x 2	32,895 x 2	32,550	4,799	108,831
Lb	6,270 x 2	72,520 x 2	10,580	168,162	6,270 x 2	72,520x 2	71,766	10,580	239,926



REFUEL

The refuel control panel is located in the lower surface of the fuselage just aft of the undercarriage bay (see Figure 4). From this panel the following functions are performed:

- ○ automatic refuel (pre-selection of the total fuel required on board),
- ○ individual tank refuel,
- ○ intertank transfers,
- ○ defuel.

Auto refuel under FCMC control is the primary means to fill the aircraft in the shortest time (empty to full):

- ○ A330, 2 couplings (basic), 37 min.,
- ○ A340, 4 couplings (basic), 30 min.

It ensures correct uplift and distribution. The preselected fuel quantity implies a specific fuel distribution. This is achieved by an automatic selection of tanks to be filled using the following order:

- ○ collector cells,
- ○ outer wings,
- ○ inner wings,
- ○ trim to full (A330 only),
- ○ trim up to 2.5 t (A340 only),
- ○ centre and trim remainder in proportion (A340 only).

These tanks are then filled simultaneously.

Each tank has its own fuel inlet valve and is supplied by piping linked to the refuel couplings. On the tank side of the couplings there is a separate isolation valve. Fuel cannot enter the aircraft unless the valve is open. Under certain abnormal conditions this valve will automatically shut or remain shut, e.g.:

- ○ any vent tank level sensor wet,
- ○ jettison valve failed open (A340),
- ○ control panel disagree,
- ○ overhead panel transfer push buttons engaged.

For both aircraft, wing mounted control panels and cockpit auto refuel facility are available on option. For the A330 an option exists for two refuel couplings on the left wing (in this case, using four couplings, refuel time is 30 minutes).

ENGINE FEED

Each engine is fed from its own dedicated independent collector cell (see Figure 2). Engagement of the engine master switch opens the aircraft fuel low pressure valve and the engine fuel inlet valve giving an uninterrupted flow between cell and engine.

On the A330 there is one collector cell in each inner wing tank, equipped with two main pumps which run continuously throughout the flight. A third pump (stand-by), located just outside the cell, is switched on automatically if one of the other pumps has failed.

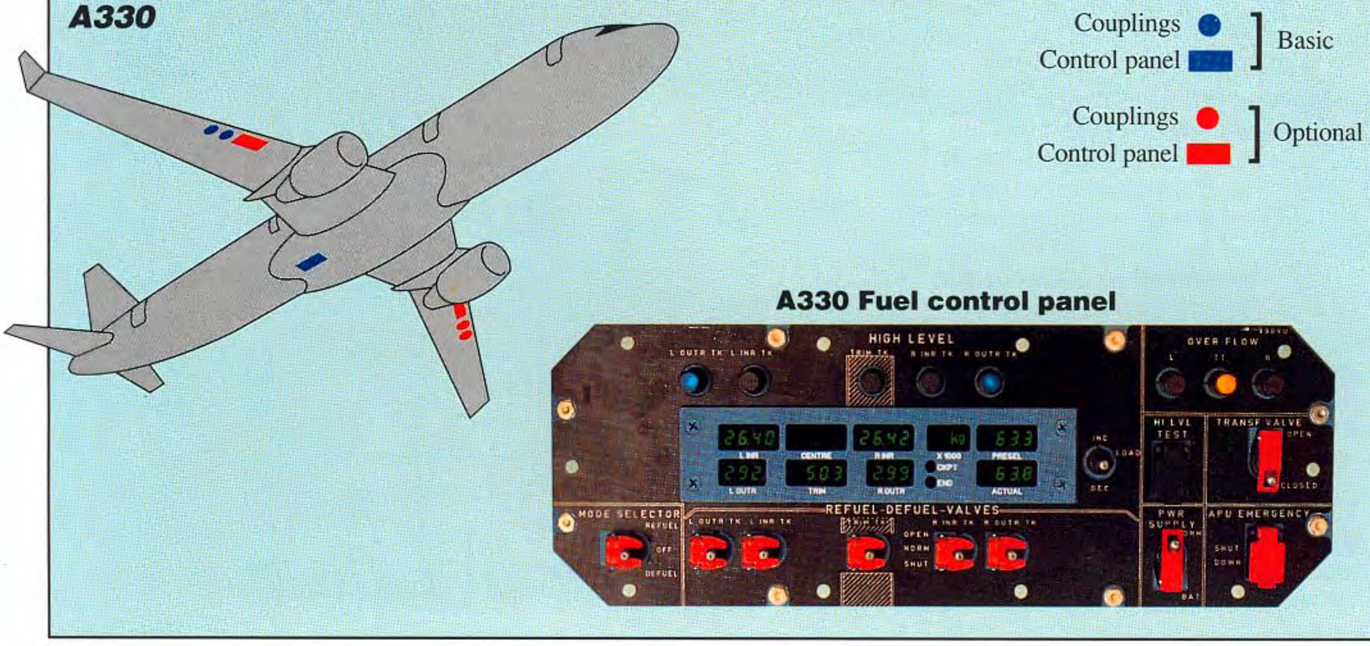
On the A340, there are two collector cells per inner wing tank; each cell is equipped with one main pump which runs continuously throughout the flight. A second pump (stand-by) installed adjacent to the main pump is switched on automatically if the main pump fails.

For both aircraft all collector cells are maintained full until the inner wing tanks are empty (see fuel transfer section). This is achieved by jet pump transfer action motivated by the main pumps and protects against negative "g".

For abnormal circumstances, wing balance, different engine feed/collector cell combinations, one crossfeed valve is provided on the A330 and four on the A340. Also for the case of an engine burst affecting inner wing tanks, valves (normally open) are provided to isolate fuel forward of the inner wing tank centre spar from fuel aft of the spar.

Figure 4

Location of the Fuel control panels and couplings



Note that all engine feed pumps are identical for both aircraft. The same pump type is also used for centre tank transfers on the A340.

IDG COOLING

On the A340, part of the engine fuel supply is diverted to cool the Integrated Drive Generator (IDG) and then returned to the inner wing tanks (see Figure 2). This occurs automatically when engine burn fuel consumption is low and electrical demands are high.

APU FEED

The APU is fed from the trim tank transfer line (see Figure 2) and is independent of the FCMC. There are two identical feed pumps (capable of operation via the static inverter) :

- The forward pump, situated in the wing centre section, draws fuel directly from the left wing collector cell. The pump outlet is connected to the trim tank line via an isolation valve.
- The rear pump is situated close to the APU downstream of the APU low pressure isolation valve.

Pump control is automatic and depends on trim tank transfer line status at the time of operation. Under abnormal conditions the forward pump may be used to pressurise the engine feed system.

JETTISON SYSTEM

A jettison system is provided on the A340 only. Once activated, all relevant valves open and the stand-by pumps run automatically (see Fig. 2). If the system is not manually stopped, it will automatically shut down at low level (an option allows pre-selection of required landing weight).

FUEL TRANSFERS

All fuel transfers pass to the inner wing tanks prior to transfer into collector cells (see Figure 2). Under normal circumstances, they are controlled by the FCMCs. The tank usage sequence is automatic and in the following priority order:

1 centre,
2 inner wings (to a prescribed level),
3 trim,
4 outer wings,
5 inner wings,
6 collector cells.

- Transfer from centre to inner wing (A340 only) is by means of two pumps located in the centre tank. Inner wing tank inlet valves are independently cycled open/closed such that the inner wing tanks remain full until the centre tank is depleted.
- Transfer to and from trim tank: see section on centre of gravity control.
- Transfer from outer to inner wing tank is by gravity. When inner wing tank fuel quantity depletes to a prescribed level, valves between the two tanks are cycled open/closed, causing stepped transfers until the outer tanks are empty.

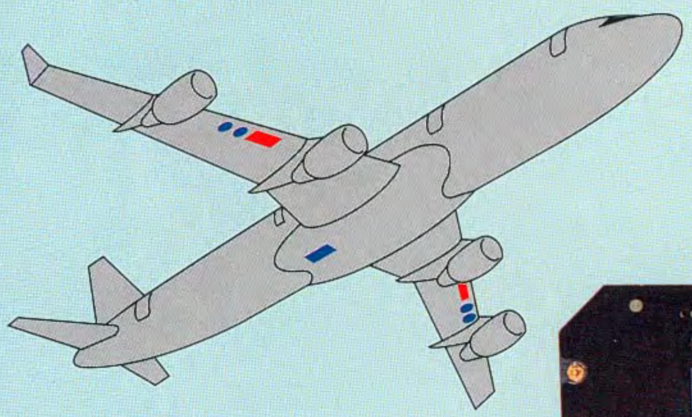
In abnormal conditions, all the above transfers may be performed manually by disengaging the relevant overhead control panel auto push-buttons.

- Transfer from inner wing to collector cells is by jet pump action as described in the engine feed section. If these pumps fail, transfer is by gravity.

CENTRE OF GRAVITY CONTROL

The performance benefits arising from this function have been demonstrated on earlier Airbus models. As a result, on the

A340



A340 Fuel control panel

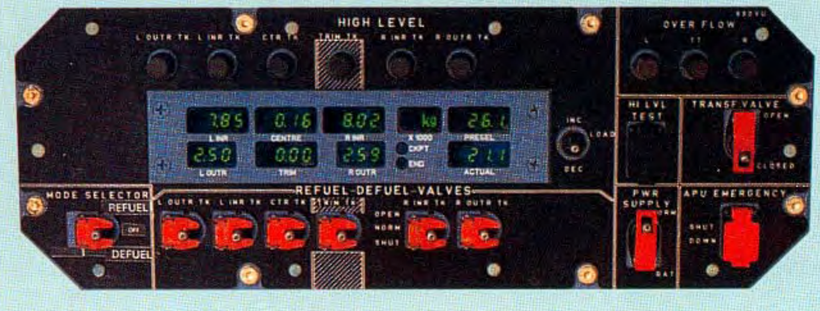
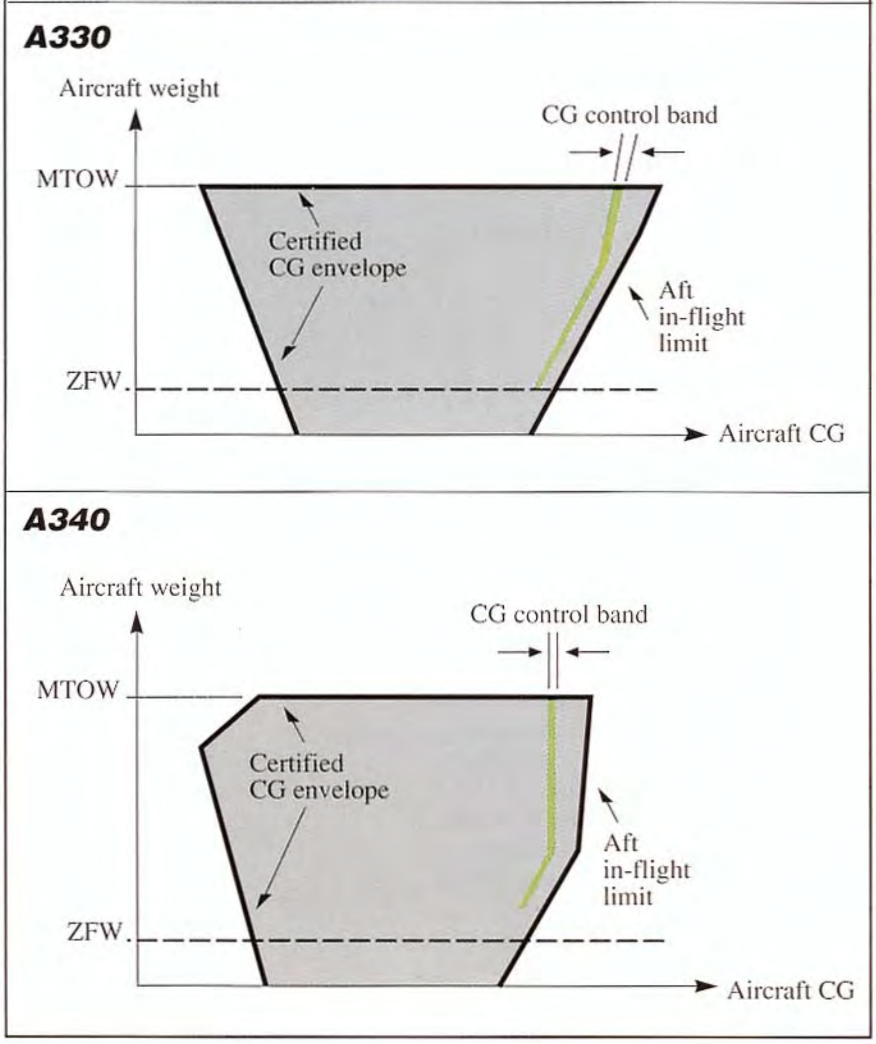


Figure 5

Centre of Gravity control band relative to certified CG envelope



A330 and A340 it became part of the basic aircraft definition.

For all Airbus aircraft equipped with centre of gravity control the fuel quantity measuring system is of primary importance, as it supplies data for the centre of gravity calculations which eventually determine centre of gravity related fuel transfers. Previous Airbus aircraft were fitted with a dedicated centre of gravity control computer. In addition to its main functions, it had also to monitor the fuel quantity measuring system in order to satisfy integrity requirements.

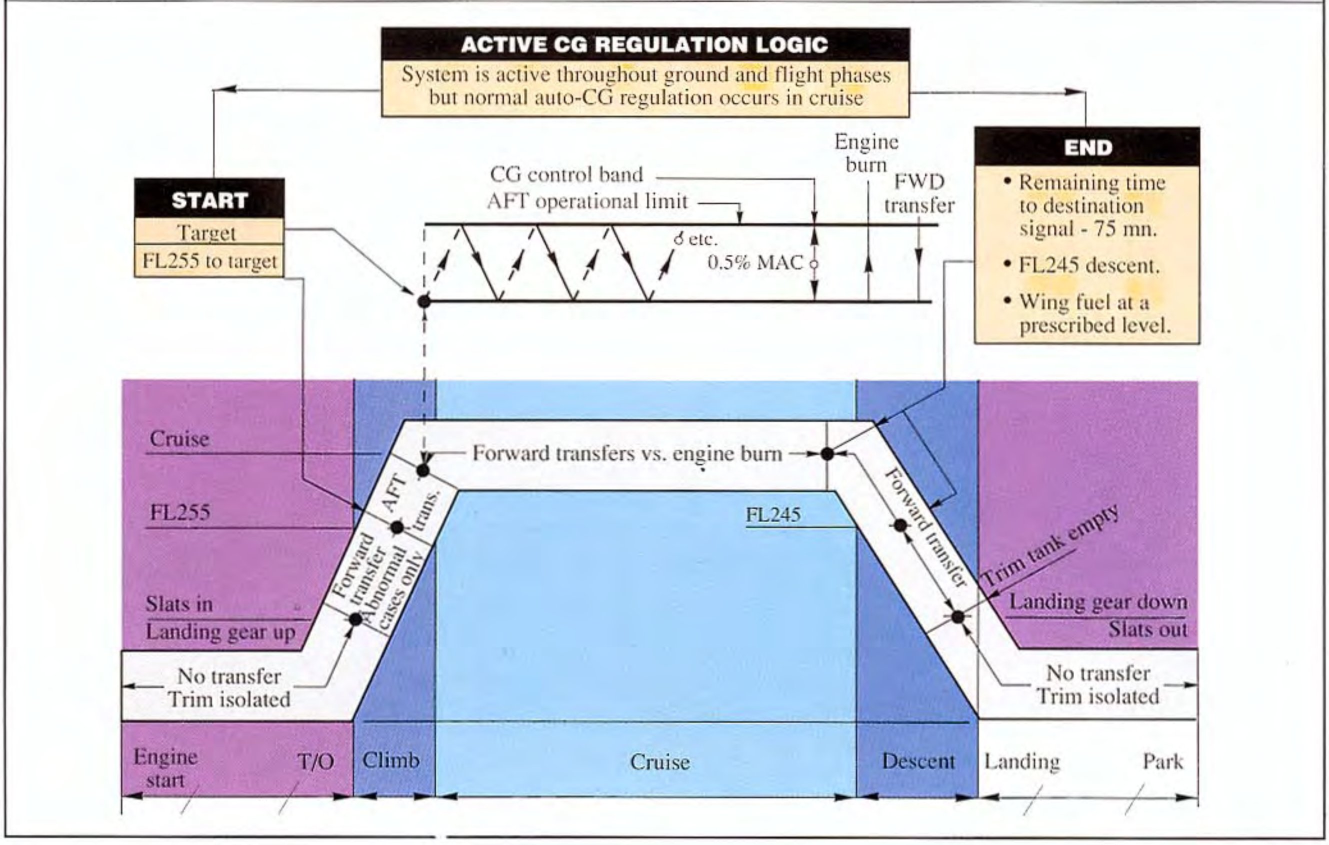
The A330 and A340 differ from earlier aircraft in that fuel quantity measurement, centre of gravity calculation, centre of gravity control and fuel in general are managed by two identical computers (FCMCs). The fuel measurement part has been designed with more redundancy and appropriate integral monitoring giving improved availability and greater operational ruggedness.

Whatever the aircraft, centre of gravity control is initiated as follows. ZFW and ZFWCG are entered into the FMGEC by the flight crew. On the A330 and A340, this information is transmitted to the FCMCs. This serves as a datum for the centre of gravity calculations which are performed by the FCMC using data from the fuel quantity measurement system. The centre of gravity display also comes from this source.

The FCMCs have a built-in centre of gravity control band (Figure 5) which is approximately 2% MAC (Mean Aero-

Figure 6

Centre of Gravity control band relative to operational flight envelope



dynamic Chord) forward of the certified aft limit . The calculated centre of gravity is compared to the target and an appropriate fuel transfer is commanded.

Figure 6 shows the centre of gravity control band relative to the operational flight envelope. Figure 7 shows typical fuel loading and depletion vectors for four different refuel cases.

Note: In a max fuel case, no aft transfer is possible. In most other cases, there will be a transfer aft at FL 255 (in climb) to reach the control band. On both aircraft this is by means of collector cell pumps. On the A340 this can also be from the centre tank pumps assuming there is fuel in the centre tank. From this point, and as a result of continuing tank depletion, the centre of gravity will move aft (initial depletion of inner wing tanks is the exception). If the target centre of gravity is reached, there will be forward transfers equivalent to 0.5% MAC (see Figure 6). This process will continue until 75 minutes before destination, when any remaining fuel in the trim tank will be transferred forward.

Figure 7

Typical refuelling and depletion vectors relative to CG control band

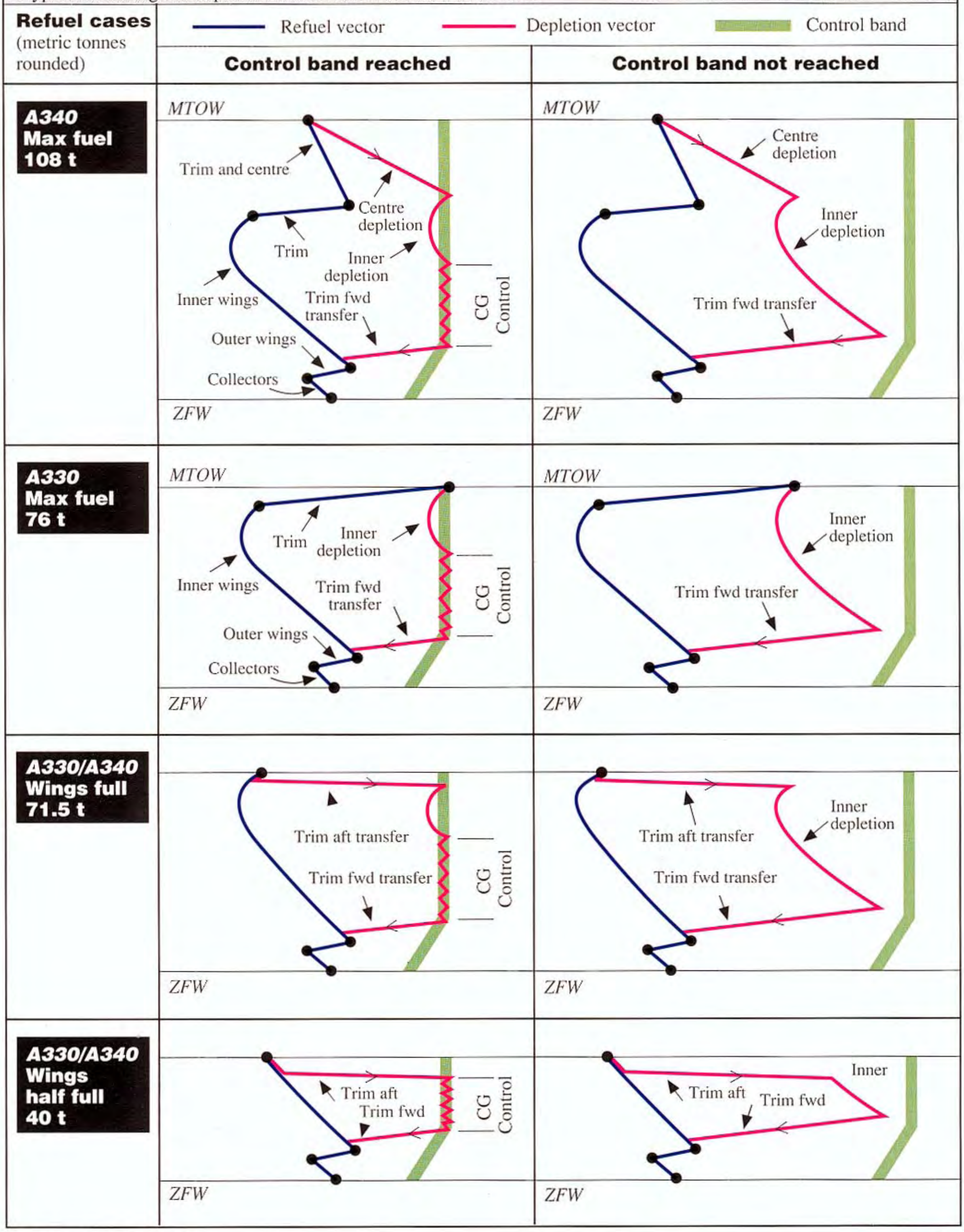


Figure 8 shows the relationship between the centre of gravity target for normal and fault conditions. The independent centre of gravity monitor uses stabiliser trim position, Mach number and N1 parameters to establish the centre of gravity.

FUEL QUANTITY MEASUREMENT SYSTEM

The fuel quantity measurement system is of the capacitance type with automatic correction for density, permittivity and attitude. It consists of approximately eighty in-tank probes, including capacitance probes, densitometers and compensators.

The two FCMCs are responsible for probe excitation, return signal conditioning, processing and computations.

The final fuel mass output is used for quantity display, refuel functions, centre of gravity calculations/display, and transfer control in general.

The philosophy is that no single fault will cause loss of any indication. There are two independent probe groups per tank. One FCMC is responsible for one group; the second FCMC is responsible for the other group; all data are known to both FCMCs. All probes are individually wired back to the computers.

Manual fuel level indicators are installed in the wings and centre tanks.

FUEL LEVEL SENSING

A system of high and low level in-tank sensors is provided, separate from the fuel quantity measurement system. It is managed by the FCMCs. The signals are used to control:

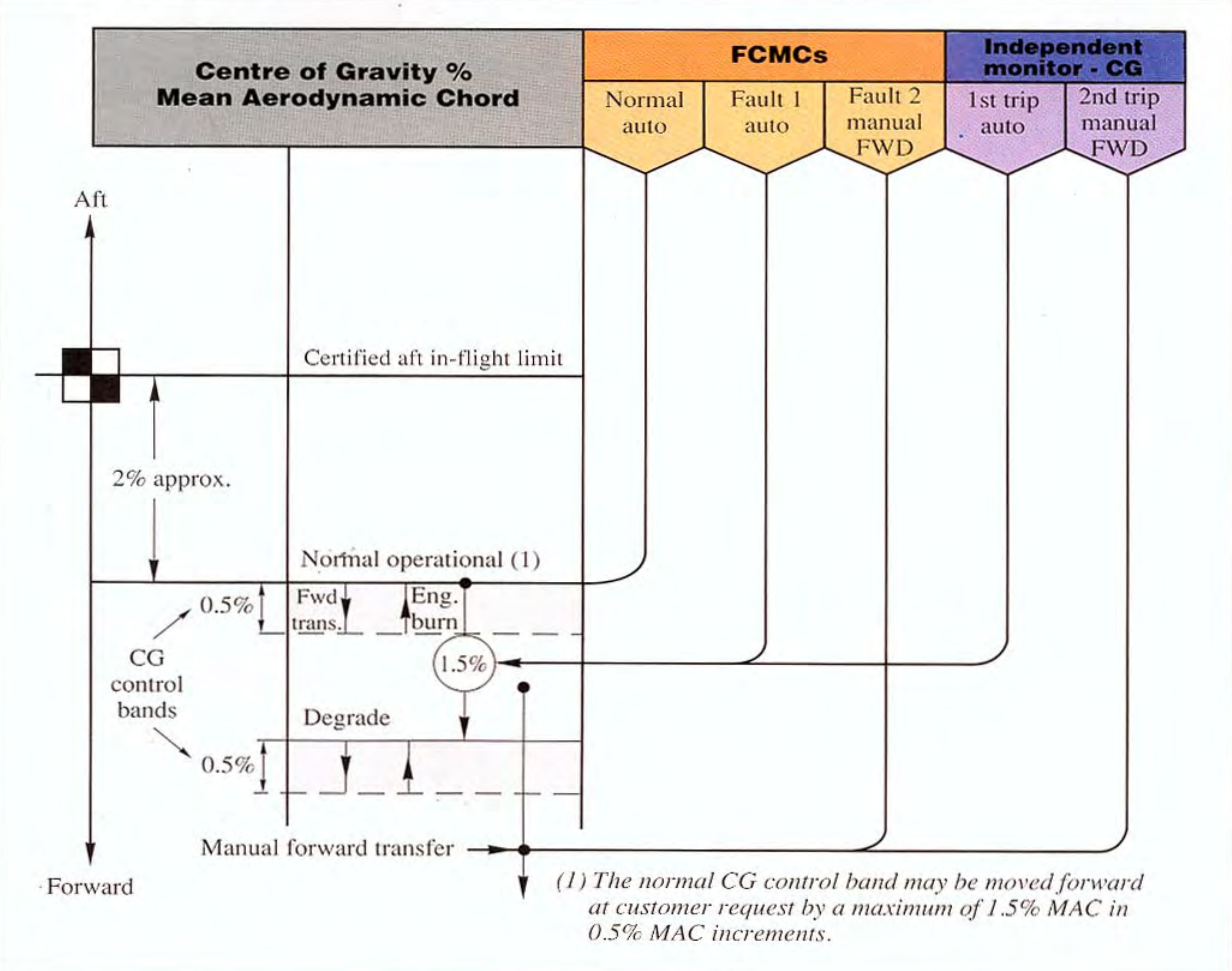
- ○ refuel,
- ○ inter tank transfers,
- ○ centre pump shut-down (when centre tank is empty - A340),
- ○ trim tank isolation when empty,
- ○ overflow protection,
- ○ indication of low fuel state.

FUEL TEMPERATURE MEASUREMENT

Dual element in-tank temperature sensors through the FCMC provide ECAM fuel temperature display for outer wing tank, trim tank and engine feed. On both aircraft the signals are used to generate low fuel temperature warnings. On the A340, they are also used in IDG cooling control.

Figure 8

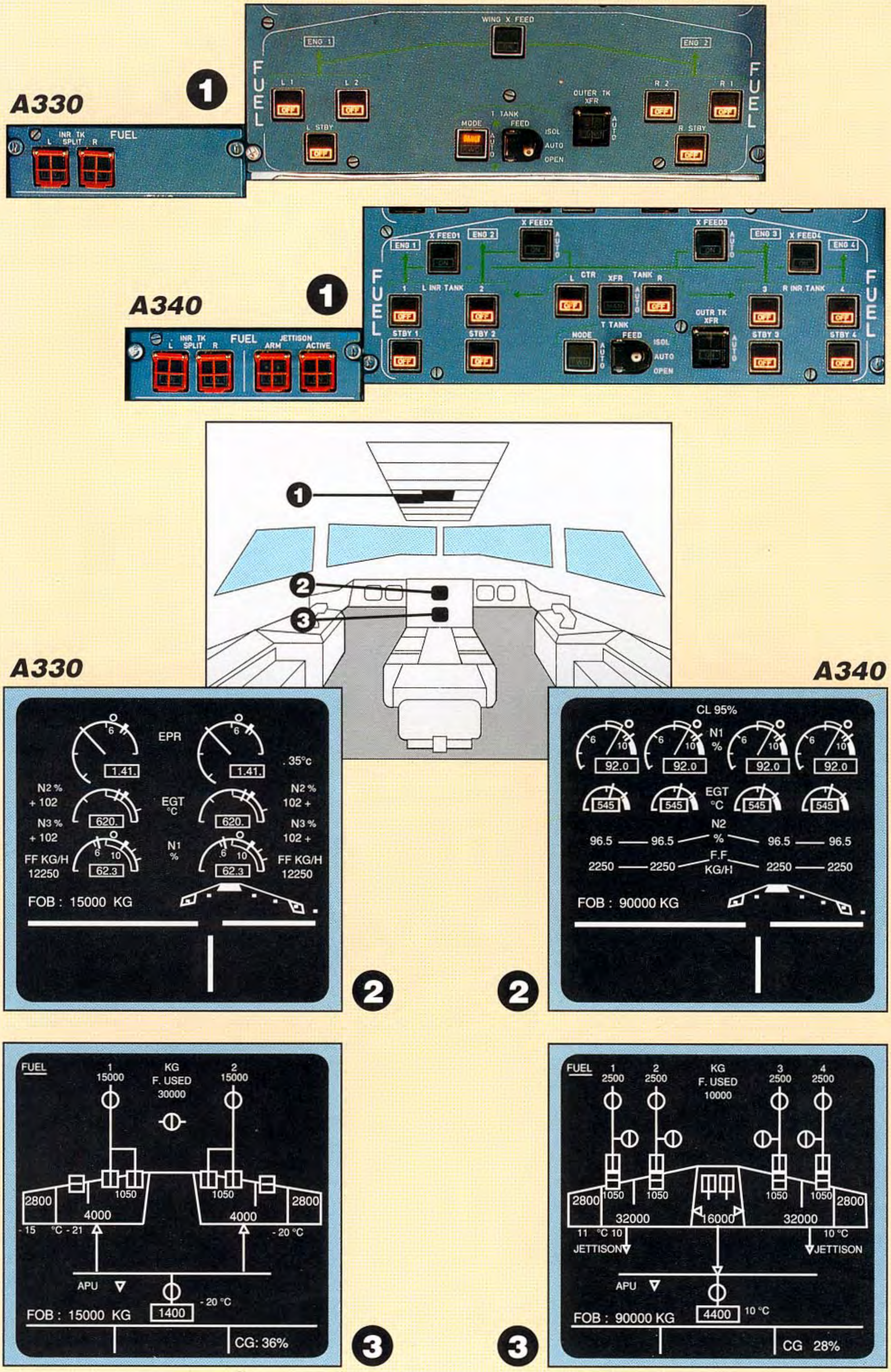
Centre of Gravity control band- Normal and with faults



(1) The normal CG control band may be moved forward at customer request by a maximum of 1.5% MAC in 0.5% MAC increments.

Figure 9

Cockpit control panels and displays



FCMC MONITORING

Each FCMC has a control and monitoring channel. Only one FCMC is master at a given time; all input data are available to both FCMCs. Power up Bite and continuous in-flight monitoring allows for warning generation: also, through the interfacing with the Centralised Maintenance System (CMS), fuel system faults are identified to LRU level.

COCKPIT CONTROL PANELS AND INDICATION

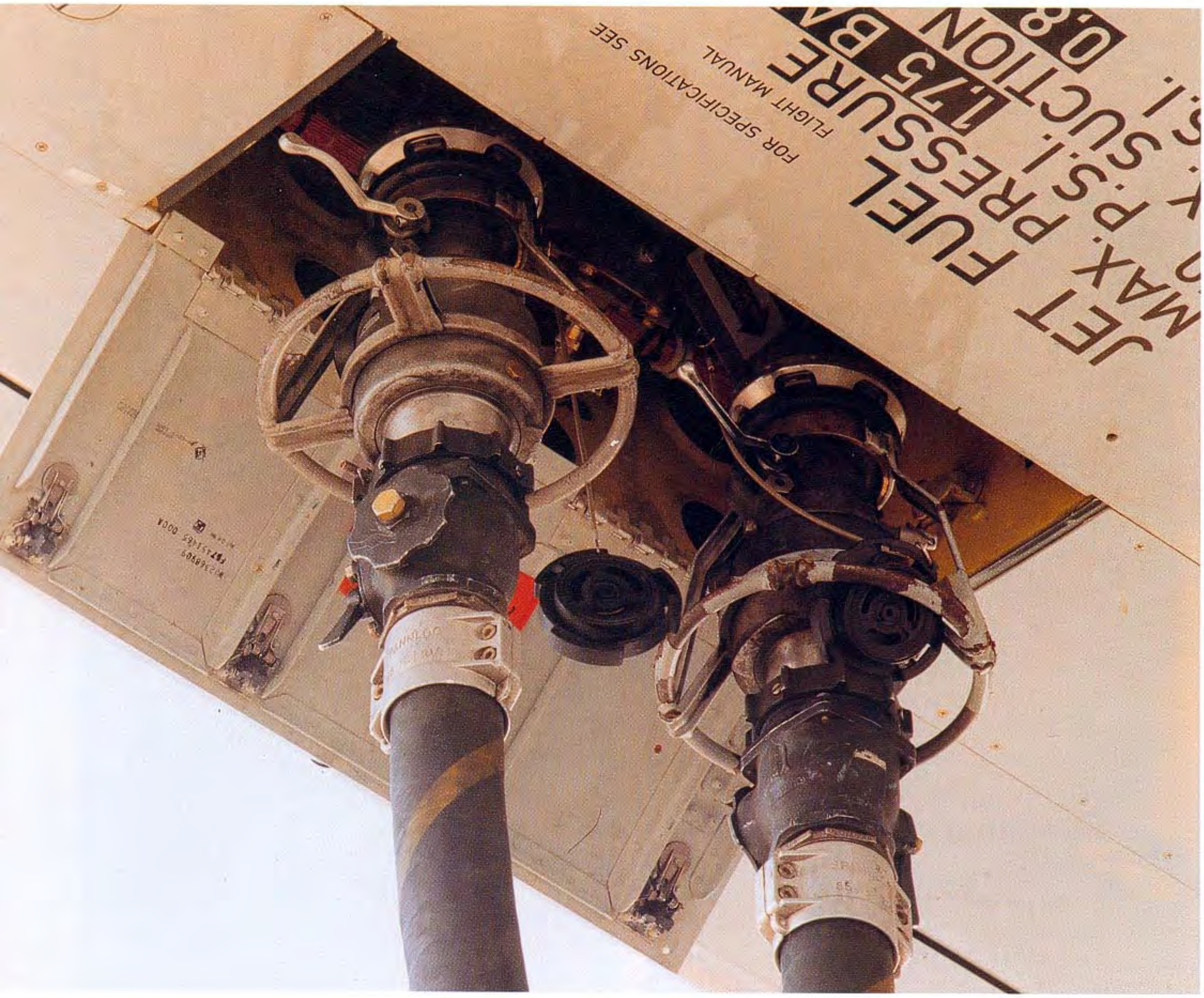
As can be seen on the main panel (see Figure 9 on page 29), there is a push-button for each engine feed pump, each cross feed valve and each transfer function, as well as a dedicated lever switch associated with trim tank isolation. In normal circumstances no crew action is required at the panel other than initialisation. Manual transfer control is by disengagement of transfer switches.

Adjacent to the main panel are the push-buttons for jettison (A340) and inner wing tank split (isolation valve). System display including fuel quantity, fuel temperature and aircraft centre of gravity is also illustrated. Warnings appear on the engine display as well as total fuel on board.

CONCLUSION

A330 and A340 are a new generation of aircraft which will satisfy medium to ultra long-range airline requirements well into the twenty-first century.

The fuel system, like other on-board systems, is designed to meet these requirements with minimum crew intervention, minimum maintenance activity and with simple servicing. ■



FIELD SERVICE REPRESENTATIVES

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Telefax: 33 (61) 93 49 64 Telephone: 33 (61) 93 38 79

LOCATION	COUNTRIES	TELEFAX	TELEPHONE	SITA
ABU DHABI	United Arab Emirates	9 712 757097	9 712 7067702	-
ALGIERS	Algeria	213 (2) 507352	213 (2) 507352	ALGTZAH
AMSTERDAM	Netherlands	1 (20) 6484175	31 (20) 6485005	AMSBI7X
AMMAN	Jordan	962 (8) 51195	962 (8) 51284	AMMAIRJ
ATHENS	Greece	30 (1) 9832479	30 (1) 9818581	ATHEYOA
ATLANTA	USA	1 (404) 7627401	1 (404) 7620011	-
BAHRAIN	Bahrain	973 320584	973 327262	BAHELGF
BANGKOK	Thailand	66 (2) 5311940	66 (2) 5310076	BKKZUTG
BOMBAY	India	91 (22) 6113691	91 (22) 6128203	BOMEAAI
BUCHAREST	Romania	40 (1) 3129771	40 (1) 3129763	-
CAIRO	Egypt	202 672472	202 671991	CAIESMS
CANCUN	Mexico	52 98860096	52 98860096	CUNCUCO
CARACAS	Venezuela	58 (31) 29041	58 (16) 228983	CCSTZVA
CARDIFF	Wales	44 (446) 711995	44 (446) 711767	-
CINCINNATI	USA	1 (606) 283 7638	1 (606) 283 7637	-
COLOMBO	Sri Lanka	94 (1) 453893	94 (1) 453893	-
COPENHAGEN	Denmark	45 32456496	45 32454501 Ext. 279	CPHBI7X
DAKAR	Senegal	221 201148	221 201615	DKRRFRK
DELHI	India	91 (11) 5452541	91 (11) 5452273	DELEEIC
DUBAI	United Arab Emirates	971 (4) 822273	971 (4) 822519	-
FRANKFURT	Germany	49 (69) 6964699	49 (69) 6963947	-
HOUSTON	USA	1 (713) 9853624	1 (713) 9853623	-
ISTANBUL	Turkey	90 (1) 5735521	90 (1) 5740907	-
JAKARTA	Indonesia	62 (21) 5501943	62 (21) 5501993	JKTBI7X
JEDDAH	Saudi Arabia	966 (2) 6857712	966 (2) 6842864	JEDMISV
JOHANNESBURG	South Africa	27 (11) 9784309	27 (11) 9783361	-
KARACHI	Pakistan	92 (21) 4570604	92 (21) 4570604	KHIVEPK
KUALA LUMPUR	Malaysia	60 (3) 7462230	60 (3) 7402470	KULBAMH
KUWAIT	Kuwait	965 4342567	965 4742193	KWIEJKU
LAGOS	Nigeria	-	234 (1) 900471 Ext 117	LOSSOWT
LARNACA	Cyprus	357 (4) 624285	357 (4) 620881	LCAABCY
LISBON	Portugal	351 (1) 8474444	351 (1) 807032	LISBICR
LONDON (LHR)	England	44 (81) 5626785	44 (81) 5626786	LHRYWBA
LOS ANGELES	USA	1 (310) 6465888	1 (310) 6465848	LAXQCCO
LUTON	England	44 (582) 483826	44 (582) 398706	LONBI7X
MADRID	Spain	34 (1) 3290708	34 (1) 3291447	-
MALAGA	Spain	34 (5) 2245514	34 (5) 2246354	AGPMMOB
MALTA	Malta	356 244446	356 993013	MLAEZKM
MANCHESTER	England	44 (61) 4892335	44 (61) 4892333	MANEEDP
MANILA	Philippines	63 (2) 8310834	63 (2) 8315444	MNLEUPR
MEXICO CITY	Mexico	52 (5) 7855195	52 (5) 7843874	MEXVTMX
MELBOURNE	Australia	61 (3) 3382281	61 (3) 3380038	-
MIAMI	USA	1 (305) 8712322	1 (305) 8711441	-
MINNEAPOLIS	USA	1 (612) 7260414	1 (612) 7260431	-
MONTREAL	Canada	1 (514) 4226310	1 (514) 4226340	YULEEAC
MOSCOW	Russia	7095 5784658	7095 5784658	SVOEISU
NAIROBI	Kenya	254 (2) 822763	254 (2) 822763	NBOECKQ
PARIS (CDG)	France	33 (1) 48642548	33 (1) 48642235	PARBI7X
PARIS (ORY)	France	33 (1) 49780185	33 (1) 49780288	ORYASAF
PHOENIX	USA	1 (602) 6937444	1 (602) 6937445	-
PRAGUE	Czech Republic	42 (2) 3164275	42 (2) 3164727	PRGBI7X
PUSAN	South Korea	82 (51) 9714106	82 (51) 9716977	PUSXSKE
ROME	Italy	39 (6) 6529077	39 (6) 65010564	FCOYSAZ
SAN JOSE	Costa Rica	506 412228	506 417223	SJOMALR
SANTA CRUZ	Bolivia	591 (3) 425680	591 (3) 93408	SRZMALB
SEOUL	South Korea	82 (2) 6643219	82 (2) 6654417	SELXSKE
SHANGAI	China	86 (21) 2556671	86 (21) 2556671	-
SINGAPORE	Singapore	65 (5) 425380	65 (5) 455027	-
SOFIA	Bulgaria	359 (2) 796170	359 (2) 796170	SOFGALZ
TAIPEI	Taiwan	886 (2) 5450438	886 (2) 5450424	TPEBI7X
TEHERAN	Iran	-	98 (21) 9112773	THRMBIR
TOKYO	Japan	81 (3) 37478270	81 (3) 37478271	-
TORONTO	Canada	1 (416) 6711137	1 (416) 6122032	YYZBI7X
TULSA	USA	1 (918) 2922581	1 (918) 2923227	HDQMRAA
TUNIS	Tunisia	216 (1) 750855	216 (1) 750639	TUNTITU
VANCOUVER	Canada	1 (604) 2763548	1 (604) 2763776	YVRBI7X
VIENNA	Austria	43 (1) 711103235	43 (1) 711103688	-
WASHINGTON	USA	1 (713) 9853624	1 (713) 9853623	-
WINSTON SALEM	USA	1 (919) 7670784	1 (919) 7676300	-
XIAN	China	86 (29) 741203	86 (29) 798510	-
ZURICH	Switzerland	41 (1) 8102383	41 (1) 8127727	ZRHZESR

ADVANCED TECHNOLOGY AND THE PILOT

THE ULTIMATE COCKPIT FOR EXTENDED LONG RANGE OPERATIONS

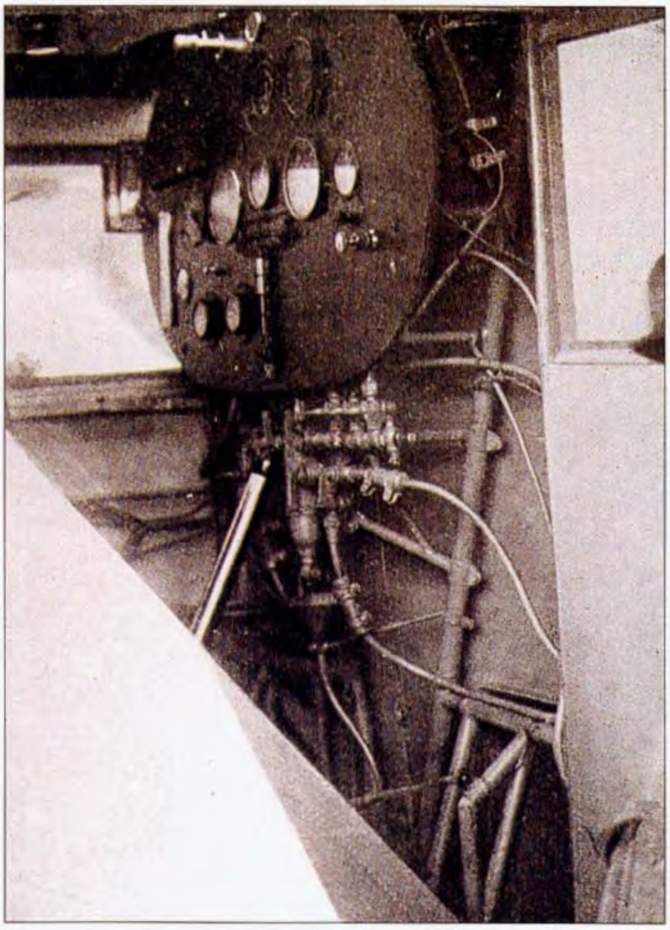
PART II

Cockpit technology has now become so sophisticated that instrumentation and even forward vision can be reduced to almost insignificant levels.

The elimination of the windscreen and development of a simple side-stick controller allows location of the instrument panel in the optimum position for pilot vision. The controllable periscope provides adequate forward vision on the few occasions it is actually needed.

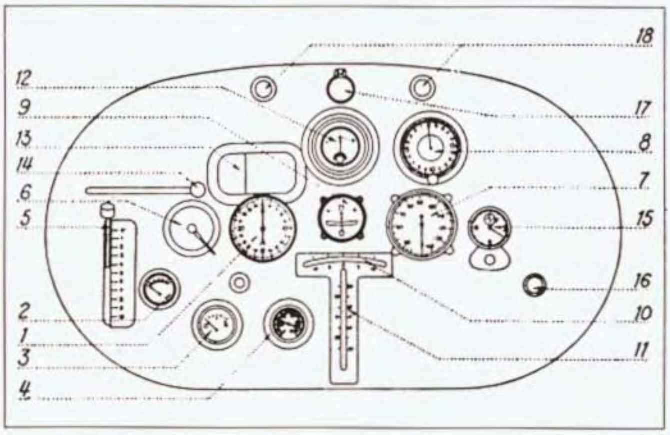
In recognition of the increasing number of female pilots now entering airline service, the addition of a mirror on the instrument panel will be of particular interest. Such attention to detail highlights the effort manufacturers now expend to maintain pilot attention and awareness, particularly during long over-water flights.

Cockpit of the Spirit of St. Louis 1927



Schematic diagram of the instrument panel

1. *Rev counter*
2. *Oil pressure gauge*
3. *Fuel pressure gauge*
4. *Oil temperature gauge*
5. *Altitude correction knob*
6. *Magneto selector*
7. *Air-speed indicator*
8. *Altimeter*
9. *Turn and tank indicator*
10. *Roll indicator*
11. *Pitch indicator*
12. *Millivolt meter for magnetic flux compass*
13. *Periscope*
14. *Periscope operating lever*
15. *Clock*
16. *Instrument panel lights*
17. *Mirror*




A340
THE A340 FLIES FURTHER
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