HYDRAULIC SYSTEM - WORKING PRACTICES
Airbus Product Support - Hydraulic Systems Group

OPERATIONAL RELIABILITY PERFORMANCE
Achim Krapp

AIRBUS SERVICE BULLETIN COMPUTERISATION
Henri Thoa

MATERIALS SYMPOSIUM

A300/A310/A300-600 TECHNICAL SYMPOSIUM

DRAG REDUCTION
Jean-Pierre Robert

FIELD SERVICE REPRESENTATIVES

DRAG REDUCTION - PART 2
Hydraulic leaks have been a nuisance since the first day a hydraulic system was installed in an aircraft. In today’s aircraft with their greatly increased size and multiple high pressure systems, leaks can be even more of a nuisance. However with good design and good maintenance practice they can be avoided. This article will certainly help you to verify good maintenance practices and thus reduce the number of leaks and perhaps even to avoid them.
HANDLE WITH CARE

Phosphate ester based hydraulic fluids, such as Chevron's Hyjet and Monsanto's Skydrol, are extremely aggressive fluids which have to be treated with great care. They attack ordinary paint surfaces and non metallic materials with equal vigor. Protective clothing, and particularly goggles, must be worn when working with these fluids. Protective surfaces must be repaired the moment chips or scratches are observed.

LEAKING PIPELINES

The majority of hydraulic leaks, about 60%, are to be found in the pipelines, at loose or damaged unions or damaged seals. These are really simple plumbing problems which can be permanently fixed if some basic rules are followed. It was probably non-adherence to these rules which is causing hydraulic fluid to run down someone's sleeve right now. Bad practice aided by vibration quickly causes pipes and fittings to move and leak.

Properly installed flareless fittings form a strong, fluid-tight joint.

LEAKING EQUIPMENT

Less than 40% of leaks stem from pumps, valves, etc., and modifications are available (Table 1) to correct them. However the correct practices must be observed when reinstalling these components to avoid any further leaks.

GOOD PRACTICE

Adhering to the following basic rules will significantly reduce the likelihood of future trouble:

**Cleanliness**

Maintain a clean working environment. Contamination of a hydraulic system by foreign objects such as swarf, dust, dirt, fragments of paint, etc., may lead to wear of the various components in the system and thus cause a malfunction. It is of the utmost importance that adequate precautions are taken at all times to ensure scrupulous cleanliness.

Remember that hydraulic fluid is itself a contaminant and may have stripped off paint or decomposed adhesive tape, in the vicinity of the leak and thus, where the system may be opened. Therefore, as far as possible, always clean the area around the joint to be opened, before opening it.

Always cap open lines using the approved caps. Stuffing a rag into a pipe is not an approved method since it is an inefficient cap and can itself contaminate the system with flocculent particles. Equally tape or paper should not be used (Figure 1).

**Figure 1**

Proper cap installation (flareless Harrison fittings)

Correct installation

Incorrect installations

Proper cap installation on pipes.

A dirty environment can lead to malfunction and wear.

**Elbow unions**

These unions are simple in design and simple to install. However they are frequently installed incorrectly and can be the cause of significant leaks. It is imperative that the following instructions are followed:

- Install the lock nut with the flat face first and screw it just far enough on to the second set of threads until the undercut on the union is fully visible on the counterbore side of the nut.
- Treat a new “O” ring and packing washer with great care especially when
Table 1

<table>
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<th>Component</th>
<th>Part Number</th>
<th>Vendor SB</th>
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</tr>
</tbody>
</table>

Figure 2

Elbow union installation

- Elbow
- Lock nut
- Packing washer
- "O" ring
- Pipe nut

Correct installation Incorrect installation

Passing them over the threads of a union. They should be coated with hydraulic fluid or lubricant MCS-352 prior to installation to avoid twisting, tearing and chipping.

- Install the packing washer into the counterbore of the locknut, then the "O" ring in the undercut of the union against the packing washer (Figure 2).
- Screw the elbow (with its lock nut) into the manifold until the "O" ring makes contact, taking care not to turn the lock nut separately. This is to make sure that the "O" ring and packing washer ride in the undercut and are not squeezed on to the threads when the lock nut is tightened.
- Align the elbow (complete with lock nut) with the associated pipe by unscrewing the elbow by a maximum of one turn, taking care not to turn the lock nut separately. Connect the pipe and loosely tighten the pipe nut.
- Torque tighten the lock nut to the required value. (See torque tightening).

The elbow union with a spanner while its lock nut is being tightened to ensure a stress free installation. An elbow union being held in an unnatural position, only by its lock nut and not in the position the connecting pipe should lie in, will vibrate to its natural position, and leak, in a very short time.
- Check the alignment of the pipe. If the pipe nut can be finger-tightened the alignment is correct. Continue to hold the elbow in position with a spanner and torque tighten the pipe nut (Figure 5).

Remember:

Do not use pointed, sharp or metal tools to remove "O" rings, seals or backing rings since sharp edges may damage their housings or sealing surfaces (Figure 3).

Remember used "O" rings and other seals should never be re-installed. Once they have been compressed they will never regain their original shape. Only re-install used packing washers if you are absolutely sure that they are undamaged. If you have the slightest doubt install new ones. It is recommended to replace leather (MS28777) with teflon (MS28773) packing washers, since they have greater resistance to swelling. Swollen packing washers can result in incorrect torque of the locknut and consequent leakage.

Pipes

Hydraulic system supply lines are designed to withstand the 3000 p.s.i. (206 bars) system nominal operating pressure. Consequently the pipes are very strong and resist efforts to bend or stretch them. They are unpainted.
When installing a pipe always ensure that it fits squarely into the fittings and is the right length. If it does not fit, stop, think and investigate why it does not fit before proceeding. Never try to pull a pipe
Correct installation avoids that pipes are stressed into clamps or line blocks.

Correct installation of ties avoids chafing.

Make sure that pipes are not forced into clamps or line blocks. A stressed installation will certainly lead to a leak and perhaps a cracked pipe.

If clamps and line blocks are removed so that a pipe or component can be replaced ensure that they are re-installed again. Improperly supported pipes will vibrate causing fretting and loosening of fittings.

**Stress free installations**

To install a pipe in a stress-free manner there are four steps to be followed:

- **Position** the pipe with the clamps loose. This allows the pipe and the unions to align freely.
- **Bottom** the pipe ends in the unions and check that the pipe is sitting comfortably in the clamps.
- **Hand** tighten the pipe nuts and tighten the clamps.
- **Hold** the unions steady and torque tighten the pipe nuts.

If the pipe is drawn into place by the pipe nuts or clamps or both, the resulting stress introduced into the pipe will surely result in a leak at some stage.

**Chafing**

Always be on the look out for the risk of chafing. A minimum clearance of 0.25 of an inch (6 mm) from fixed structure, of 0.75 of an inch (18 mm) from control rods and rigid moving parts and of 1.0 inch (25 mm) from control cables, must be maintained, otherwise vibration and movement may cause chafing. Particular care is necessary to ensure that adequate clearance is maintained between pipes and moving parts, and tests should be carried out to ensure that clearance is satisfactory throughout the full range of movement of the associated part. Consideration should also be given to effects which may not be possible to simulate, such as an increase...
in tyre diameter due to centrifugal force, or in width due to ageing.

If it is judged that a pipe could chafe and nylon ties are used to restrain it, be careful not to put stress into the pipe being tied down or the pipe it is being tied to.

Bobbins

As far as is possible hydraulic components such as filters, valves, pressure switches etc. are mounted on manifolds and connected hydraulically through bobbins. Each bobbin is fitted with a square seal and a packing washer on the end which fits into the component and an "O" ring and packing washer on the end which fits into the manifold. The bobbin has been designed this way so that when a component is removed from the manifold the bobbin will come off with it. This allows the mechanic to fit blanking caps into the open orifices in the manifold immediately, thus limiting the loss of fluid. The bobbins can then be removed from the component at leisure to change the seals.

Figure 4

Bobbin

- "O" ring
- Square seal

Identification groove

When replacing the component it is essential that the bobbin is fitted with the square seal end in the component. An identification groove (Figure 4) is cut in the "O" ring end of the bobbin to indicate correct fitment. Seal, "O" ring and packing washer should be smeared with MCS-352 lubricant or hydraulic fluid. Fitting the bobbin into the component first, rather than into the manifold, allows the mechanic to fit the bobbin correctly without being under pressure because all the system fluid is running over his feet. The component complete with bobbin(s) can then be fitted into the manifold quickly with the minimum loss of fluid.

Torque tightening

Proper torque tightening of lock nuts and pipe nuts will remove the greatest cause of hydraulic leaks. Because of the variety of sizes, materials and positions of nuts it has become impossible to guarantee their correct torque without using a torque spanner (Figure 5).

Three pieces of information are needed when determining what torque to apply to:

- material of the pipe and unions,
- diameter of the pipe,
- flared or flareless fitting.

Material

Pipes in the high pressure supply lines are unpainted and made of stainless, sometimes called corrosion resistant (CRES) steel. Torque figures are the same for stainless and titanium pipes. The nuts and fittings on stainless steel pipes are generally made of steel or stainless steel. Pipes on the low pressure and suction lines are painted and generally made of aluminium alloy, sometimes known as light alloy, but in certain areas such as in the wheel-well they may be made of stainless steel. Aluminium alloy and stainless steel return lines may have aluminium alloy or steel nuts.

Stainless steel nuts are unpainted. Steel nuts are cadmium coated. Aluminium alloy nuts are generally coloured green or blue although other colours and grey anodic treatment may sometimes be found. They vary depending on the supplier.

Diameter

Diameters are given in inches or fractions of an inch with metric conversions.

Fittings

The vast majority of pipe fittings are the flareless Harrison types. Flared pipes with AN nuts may be found on some powerplants and on some early A300s.

With these three pieces of information the correct torque values can be found in Chapter 20 of the Aircraft Maintenance Manual (AMM). The tables are laid out according to pipe diameter and type of material. The answer is clear when the pipe and its fittings are all the same material; however care must be taken when there is a mixture of materials.

For example: a one inch stainless steel pipe with a flareless fitting, in the high pressure supply line, will have a stainless steel nut and it may be attached to a stainless steel elbow which has a stainless steel lock nut. However the elbow is screwed into an aluminium alloy manifold. In this case the pipe nut should be torqued to the stainless steel figures of between 95.14 and 104.7 lb.ft (12.9 to
Examples of steel tube with alloy nut...

... of alloy tubes with alloy nuts...

... steel tubes with steel nuts.

14.2 m.daN) but the stainless steel lock nut should be torqued to the aluminium alloy figures of 85.85 to 87.47 lb ft. (11.64 to 11.86 m.daN) because it is being tightened against a light alloy face.

Having decided on the torque figure to use, lightly lubricate the threads of the nut with hydraulic fluid.

**Remember:**

*When steel and light alloy are mixed, always tighten to the light alloy figure.*

Access is not always easy on aircraft and it may be necessary to add an extension to the torque spanner. In this case the torque figure must be re-calculated as shown in the AMM. The extension must not be longer than the spanner. It is essential to use a torque spanner and the right set of torque figures. If you don't use the right figures or don't use a torque spanner one of two things is likely to happen: aluminium alloy is likely to be over tightened and stainless steel under tightened.


After working on a hydraulic system, the work area must be cleaned and dried and the reconnected pipes and unions must be leak checked.

**Leaks**

**Remember:**

*Special note should be taken of safety precautions, particularly to protect the eyes, before searching for a leak. A small leak in a high pressure system may project fluid in a nearly invisible fine spray.*

The presence of a leak is shown by presence of fluid or an accumulation of dirt or dust in the vicinity of the leak. Depressurise the system and clean the area.

The union may be tightened but should not be over tightened in an attempt to cure the leak.

**Remember:**

*Always use two spanners.*

Leaks are often caused by solid particles at the face of a joint, by misalignment, or by damage to one of the components of the joint. Loosening and retightening of a union will often cure a leak but if it does not, the coupling should be disconnected and the cause of the leak ascertained.

When repairs are finished always bleed the system in accordance with the Aircraft Maintenance Manual and be sure to check the fluid level, it may need to be replenished.

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A video film and a handbook on hydraulic practices are available from Airbus Industrie, Product Support (AI/ST) 31707 Blagnac Cedex, France. Airbus Industrie is grateful to the CAA for the advice provided in their Civil Aircraft Inspection Procedures, and to Continental Airlines for their aid in writing this article.
Software and hardware developments in the field of word and data processing have been so significant in recent years that no one can claim to be unaware of the advantages to be gained from their exploitation in their day to day work. The Electronic Messaging system in use within Airbus Industrie today allows instant and unambiguous communication between staff at headquarters in Toulouse and those located at field service stations around the world. This system has proven beyond any doubt that computerisation of aircraft documentation can provide enormous advantages for Airbus Industrie and its customers in terms of production time and quality.

One of the areas where time and quality are of the utmost importance is the provision of approved retrofit documentation in the form of a Service Bulletin. About one year ago Airbus Industrie decided that computerisation of Service Bulletins could lead to significant improvements in the service provided to its customers. Therefore a project was launched to investigate the possibility of producing Service Bulletins using workstations linked to the mainframe computer which contains data required for Service Bulletin preparation.

Preparation of a document in "electronic" form leads automatically to the possibility of distributing it electronically, and electronic distribution requires that the sender and the receiver both speak the same electronic language. It was therefore necessary to ensure that our Service Bulletins conformed to an international standard which would be acceptable to our customers. We chose the Standard Generalised Mark-up Language (SGML) as the basis for the structure of our document.

A team of about ten people consisting of Service Bulletin authors and EDP (Electronic Data Processing) specialists have been working on the project. They have produced a Document Type Definition (DTD), corresponding to the basic ATA 100 Service Bulletin definition, with some amendments to cater for Airbus Industrie's format.
Airbus Industrie's initial objectives were:
- reduction of Service Bulletin production time,
- standardisation of Service Bulletin format,
- further improvement of Service Bulletin quality by:
  → on line consultation and automatic processing of the information in other Airbus data bases (effectivity, spares, wiring and other manuals, including illustrations),
  → automatic output of standard sentences,
  → no possibility of cross reference mistakes between originator and Service Bulletin content,
  → homogeneity of data within the Service Bulletin;
- preparation for electronic dispatch.

The first investigations, working group analyses and variation in hardware available, highlighted the need for a common language to achieve our objectives. Therefore, the Document Type Definition was developed to define the structure of an Airbus Service Bulletin, so that it can be written at any work station without deviation from a constant format. Sufficient flexibility remains however to cover the variety of information and layout difference necessary for Service Bulletins.

The DTD in its present form is designed as a means of controlling the content of the document for Airbus' internal needs, and has been successfully tested using a sample Service Bulletin.

The whole Service Bulletin computerisation project has been presented to some airlines and discussions revealed positive interest in this Airbus project. Although all of them appreciated the effort to produce computerised Service Bulletins in hardcopy format, they expressed more interest in future possibility of electronic dispatch, and requested assurances that manufacturers would standardise their method of data transmission.
INTERNATIONAL STANDARDS

SGML
This Standard Generalised Markup Language (SGML) for text (ISO 8870) is aimed to support standard interchange of documents, independently from their physical presentation. It is a "metalanguage" specification that guides the DTD.

DTD
A Document Type Definition is a formal description of the logical structure of a document class. Then all the documents that pertain to this class must be tagged according to the corresponding DTD and can then be interchanged in an SGML standard way.

CCITT Group 4
The Consultative Committee International Telegraphic and Telephonic Group 4 transmits electronic illustrations operating on the "Raster" principle (eg: newspaper photographs and telecopy).

CGM
The Computer Graphic Metafile is also a standard for transmission of illustrations. It operates on the "vector" principle and retains the drawing structure in memory so that future changes can be processed. At present this standard is not mature enough for our needs.

SB revision process
When dealing with SGML we must forget our conventional ideas about paper documentation. SGML cannot cope currently with pagination for document transmission, so we have to forget the concept of page-based revisions. To meet both hard copy and electronic dispatch requirements, Airbus Industrie will propose complete re-issue of the Service Bulletins every time they are revised. Service Bulletin change notice procedure however remains unchanged.

FUTURE DEVELOPMENTS

Short term
Under the guidance of ATA, manufacturers and airlines have just started discussions to harmonise the Service Bulletin DTD with the objective of producing an ATA approved DTD which can be provided to all airlines, and which would be capable of processing a Service Bulletin from any manufacturer. Due to both internal and external requirements, Airbus Industrie will maintain the existing DTD for internal Service Bulletin processing and is participating in the ATA definition of an industry standard DTD, which would be used for dispatching Service Bulletins to the airlines. Hard copy Service Bulletin production will be operational by the end of 1992.

Long term
Long term development depends on airline requirements and cost effectiveness.

With the advent of an ATA approved DTD available to those airlines which require it, Airbus Industrie will be able to achieve direct transfer of data to airlines. Although at first it is envisaged that this transfer will be via diskette or cartridge, there is no reason why airlines should not receive the data via an electronic message system. During our meetings with the airlines, all of them expressed strong interest in the possibility of instant access to our data as soon as it is available, based on a "menu" proposed electro-

cally by Airbus Industrie. It could be envisaged that a dialogue between customer and Airbus would allow a system to be built for feedback information from the customer.

The current Airbus DTD is available and can be supplied to any interested customer. Any suggestion on the subject of DTD content or Service Bulletin computerisation in general is welcomed and would be thoroughly analysed in a positive way. Airbus Industrie can provide airlines with a technical specification of material required as well as an estimate of initial investment and operating cost.

The above is limited to Airbus Service Bulletin production but Airbus Industrie intends to present this programme to their major vendors to inform them of the benefits of Service Bulletins computerisation.

CONCLUSION

Computerisation will lead to significant improvements in the Service Bulletin world, particularly in the control of content quality and high speed delivery. The possibility of electronic transfer of Service Bulletins is something worth striving for.

In the context of quality improvement, Service Bulletin computerisation will complement other actions which are now being undertaken, such as trial installations and video films of complex Service Bulletin accomplishment.
AIRBUS INDUSTRIE MATERIALS SYMPOSIUM
A PARTNERSHIP FOR PROFIT
ATHENS (GREECE), 17-20 FEBRUARY 1992

The sub-title and central theme of this year’s Airbus Industrie Materials Symposium sounds like a motto. Indeed airlines, airframe manufacturers and equipment suppliers are links in the same chain. We are business partners, and each of us has to get a fair share of the overall profit through his own part of the business.

Organized by Airbus Industrie, with the contribution of Olympic Airways and the sponsorship of over one hundred suppliers.

For three days, over 320 representatives from customer airlines, Airbus suppliers and partners and Airbus Industrie itself came from all over the world to meet in the historical birthplace of Western Arts, Science and Wisdom. Their common aim was to openly and frankly exchange their views on how to deal with material provisioning in the changing civil air transportation business environment.

In most of Tuesday’s and Thursday’s presentations and discussions, the availability and cost of spare equipment and parts were clearly identified as being critical parameters in the whole community’s business equation.

AIRLINES / SUPPLIERS FORUM

The whole of Wednesday was dedicated to face-to-face meetings between airlines and suppliers, where both could address individual and detailed business issues. This was a very valuable opportunity for airline buyers to have representatives from all major Airbus suppliers available in the same place and on the same day, providing a very concentrated working environment in which many problems were resolved.

WORKSHOPS

One of the highlights of the symposium was the Thursday morning workshops session. Four subjects were debated, each by three groups of fifteen to twenty-five people from both the airline and supplier communities. The subjects, main themes within the Symposium, were introduced by Airbus Industrie.

View of the workshop chaired by Thierry van der Heyden Senior Director ASCO Spares Center

Four airlines, Northwest, All Nippon Airways, Ansett and Swissair, gave short presentations giving their companies’ views on one of the topics.

With this preparatory work behind them the Symposium delegates then attacked the questions of:

- rush orders or long-term forecasting,
- alternate solutions to provisioning,
- proposals for standard exchange,
- repairs: quality, leadtime and cost.

Bearing in mind that, in this quickly changing world, one who does not move at all actually moves backward, these workshops allowed everyone to give his or her company’s view on what the future should look like. Many felt that this work was only a start on these topics.

Airbus Industrie therefore proposed to pursue this exercise with the participation of airlines and suppliers. They are invited to continue bringing forward their ideas, needs and advice on the key topics of spares provisioning and repair strategies. Further (smaller scale) meetings will be scheduled to fine-tune the new concepts hopefully coming out of this worldwide brainstorming exercise.

This event was also the starting point of other joint task forces where experience and data will be exchanged. The objectives being to locate areas where the competitiveness of Airbus Industrie and its suppliers’ products could be improved. Therefore leading ultimately to ways and means of contributing to the enhancement of Airbus operators’ own competitiveness in the market.

This is, we feel, what the concept of Partnership is all about.
Previous Symposia were held in Madrid in 1989, covering the A300, and in Brussels in 1990, covering the A310 and A300-600. Istanbul, the venue for the current Symposium, has long been the link between Europe and Asia, the place where Occidental and Oriental cultures meet, as Airbus Industrie itself is a meeting-place of many nationalities each contributing to a global outlook. At the reception which opened the Symposium, participants were welcomed by the Vice-President Technical from the national Turkish carrier, Mr Yusuf Bolayirki.

Continuing a well-established tradition, the Symposium also provided an opportunity for excellence in achievement to be recognised. Bernard Catteau, Senior Vice-President Support, presented the 1991/92 Operational Excellence Awards to three airlines, all from the Asia/Pacific Region: Australian Airlines for the A300, Singapore Airlines for the A310 and China Eastern Airlines for the A300-600. Reflecting conditions in the real world of operation, the contest for the awards was very close with little separating winners from runners-up in each category.

Four full days enabled 220 representatives from Airbus wide-body operators, major suppliers, Airbus partner companies and Airbus Industrie itself to exchange their views and experiences. The 49 operators and 20 major suppliers represented were briefed on the latest product improvements developed to enhance the operational capabilities of the Airbus wide-body fleet. Over 200 questions were submitted before the conference; these, and many other raised during the Symposium, were fully discussed during four hard working days. The Symposium provided an excellent forum for operators to deepen their awareness of product improvements which can enhance the reliability of their aircraft; Suppliers were able to meet most of our mutual customers; Airbus Industrie's understanding of operators' needs was increased, helping to ensure that airline concerns are properly addressed.

The operation reliability of the Airbus wide-body fleet is the best in the industry. However this is not a reason for Airbus and its suppliers to relax. Both parties are continuing to improve their products. Operator of A300s, A310s and A300-600s can all be confident that the support they get from Airbus Industrie and its suppliers will provide them with the means to further improve their operation.

At the presentation ceremony:
- Australian Airlines, Mr Noel R. Parkin, Regional Mgr. Europe/Middle East/Africa
- Airbus Industrie, Mr Roger Lecomte, Technical Support Director
- Turkish Airlines, Mr Yusuf Bolayirki, Vice-President Technical
- Singapore Airlines, Mr Chee Cheow, Acting Quality Control Manager
- Airbus Industrie, Mr Bernard Catteau, Senior Vice-President Support
- China Eastern Airlines, Mr Zhang Jia Jie, Vice-President Technical
DRAG REDUCTION
AN INDUSTRIAL CHALLENGE

by Jean-Pierre Robert
Airbus Industrie
Technology and
New Product Development Directorate
Advanced Aerodynamics Manager

Test section diameter: approx. 8m
Maximum tunnel diameter: 24m
Mach number in test section: 1

1. Test section and carriage
2. Fans
3. Annular air inlet
4. Vertical air inlets (2)
5. Test model preparation area
Ver the last few decades and particularly since the 1970s, all civil aircraft manufacturers have made great efforts to reduce aircraft drag. The long term aim of this operation is to reduce the specific fuel consumption of aircraft: the potential reduction of only 1% would represent savings of several million dollars for the airlines (Figure 1). The successive fuel crises (Figure 2) have increased the need for developing new technologies to be applied on new aircraft, retrofits, however, also have their uses.

Estimating the drag of a transport aircraft through calculation or wind tunnel tests must come as close as possible to the value obtained in flight. Forecast errors of the order of 1% following wind tunnel/flight transposition lead to technical and financial penalties and entail vast efforts to bring the values obtained during flight down to acceptable levels guaranteed by the aircraft manufacturers to their customer airlines.

The technologies or concepts that could significantly reduce aircraft drag often have a different reduction potential. This reduction must be clearly shown to appear in the high speed tests using large-scale models (1/10 scale). Scale models of this type do not provide the Reynolds numbers (Re)* corresponding to actual flight and this leads to wind tunnel/flight corrections that make it extremely difficult to extrapolate flight results from wind tunnel results. In some cases these corrections may be as high as 20%.

The different drag sources vary according to the type of aircraft and the type of flight mission. The drag contributions (Figure 3) may be summed up as follows:

- **Induced drag**
- **Friction drag**
- **Drag due to interference between two elements**
- **Wave drag**
- **Parasitic drag**

The proportion of each drag source may vary according to the type of aircraft, but the source breakdown (Figure 4) clearly shows the proportions of the various sources of drag for subsolar aircraft currently in operation.

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* Osborne Reynolds (died in 1912) found a value which he called “Critical Reynolds Number” (Re). Flow is laminar below Re and turbulent above it.

\[
Re = \frac{\rho p V L}{\mu}
\]

where:

- \( \rho \) - Air density
- \( p \) - Velocity
- \( L \) - Dimension (usually the chord)
- \( \mu \) - Coefficient of viscosity

Airflow characteristics differ when the size of the object varies and velocity changes, amongst other things, so an Re for a given size of model has to be corrected to correspond to a full size aircraft.

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**Figure 1**

<table>
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<th>Benefit of 1% reduction on fuel burn</th>
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</tr>
<tr>
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</tr>
<tr>
<td></td>
</tr>
<tr>
<td>A340</td>
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**Figure 2**

Average world oil price evolution (in constant 1988 US$)

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**Figure 3**

Aircraft drag breakdown

- Parasitic drag
- Wave drag
- Interference drag
- After body drag
- Induced drag
- Friction drag

**Figure 4**

Average skin friction drag breakdown

- Narrow-body
- Wide-body

**Figure 5**

Total aircraft drag (%)
FRICITION DRAG

There are various methods for reducing an aircraft's friction drag but two are currently getting the particular attention of aircraft manufacturers:
- the transition point on a surface where laminar flow is transformed into turbulent flow, particularly on an aircraft wing, should be moved as far aft as possible (Figure 5) in order to obtain lower friction coefficient (C_f) values in the presence of laminar flow, as shown in Figure 6, and by increasing the proportion of surface with laminar flow;
- modifying the turbulent structures in the boundary layer to significantly reduce the value of the turbulent friction coefficient.

Friction drag has two important generators, wings and fuselage; these together account for over 80% of the total friction drag.

So we should carefully consider all the industrial possibilities that could be called on to significantly reduce this friction drag in cruise without penalizing aspects such as take-off and landing performance, weight, cost, maintenance, safety, etc.

**Laminar Flow**

Several concepts relating to laminarity are being studied but their application is closely connected to the sweep and Reynolds number of the wings. Transition on such a surface is a function of the instabilities and the contamination encountered. These are of several types:
- Streamwise instability is caused by amplification of the Tollmien Schlichting waves and is responsible for transition when the sweep angle (φ) is less than 25° (Figure 7).
- Cross flow instability has its origin in high cross flow (φ > 25°), which makes high level Reynolds numbers the first cause of transition. This instability develops around the leading edge, where acceleration is high (Figure 7).
- Leading edge contamination is the third cause of transition, and is by no means the least. This contamination is due to propagation of disturbance from a fuselage boundary layer (Figure 8). The intensity of such disturbance is closely linked to the sweep angle and the local Reynolds numbers under consideration.

The three sources of transition are frequently found together and they prematurely trigger transition near the leading edge. According to the type of aircraft design and flight conditions (Mach, φ, Re) several methods can be considered in order to move the transition point rearwards. If the sweep angle is less than 17°, which is the case with small or business type aircraft, it is possible to define wings with optimized pressure...
gradients that help to move the transition point as far aft as possible. This method is called Natural Laminar Flow (NLF) (Figure 9).

If the sweep angle and the Reynolds numbers have high values as for the current subsonic aircraft (A310, A320, etc.) in order to maintain laminar flow on the wings it is necessary to set up a suction system either over the entire surface area or near the wing profile leading edge. This technique is called Laminar Flow Control. A combination of the two approaches is Hybrid Laminar Flow Control (HLFC) (Figure 10).

Natural Laminar Flow

Natural laminar flow (NLF) is a passive technique that uses optimized pressure gradients to maintain laminar flow over a large part of the wings. To obtain these results, maximum wing profile thickness must be as far aft as possible, but we know that the subsequent air pressure gradients lead to high intensity shocks and high wave drag. In the case of natural laminarity, structural weight penalties must be taken into account, with the knowledge that for low speed performance of this type of laminar wing design, it is not possible to envisage a high lift system (slats or Kruger). The challenge is to design wings maintaining natural laminarity with a high performance level (of, for example, the Mach number). The Mach number effect frequently increases the sweep angle which is contrary to the application of this technology.

General research taking into account all the constraints due to the introduction of this technology has been performed frequently, especially in Europe. However, savings to direct operating costs will only be seen when methods have been found to control production costs and keep the leading edges free from insect contamination and ice formation.

Laminar Flow Control

The solution frequently adopted in order to suppress the effects of the cross flow instability concerns suction of the boundary layer. Where Laminar Flow Control technology is concerned, suction makes it possible to maintain laminar flow. The entire profile, as far as the eventual transition point, must have a porous surface enabling suction. In this particular case, suction modifies the velocity profile of the boundary layer, which has the effect of significantly reducing the local skin friction coefficient (in some cases it is reduced by more than 10%). This technique requires a very fine definition of the wing profile. The results obtained depend very much on the state of the surface and on the absence of contamination by insects and dust.
Correct prediction of the transition point during flight is the manufacturers' prime task but the complexity of the suction and cleaning system that has to be integrated into the wing design (wing spar box) is also of concern. The high maintenance costs the airlines would have to pay and the energy necessary for the suction system make this technology unattractive.

**Hybrid Laminar Flow Control**

Hybrid laminar flow control is an ingenious compromise between natural and controlled laminarity. This compromise makes it possible to do away with the disadvantages described above.

By means of suction in the area between the first 15-20% of the chord and a favorable pressure gradient as for Natural Laminar Flow, the effects of cross flow instabilities are minimised and a Natural Laminar Flow may then develop in the mid-part of the wing profile (Figure 11).

Various stages must first be successfully completed at the pre-project level on a subsonic aircraft flying at a high Mach number between 0.8 and 0.9:

- Determination of the plan form, sweep angle, and wing profile,
- Determination of the type of suction (hole or slit),
- Position of transition on the wings,
- Acceptable solution to prevent contamination,
- Definition of an efficient anti-icing and high lift system,
- Effect of propulsion noise.

However, such aerodynamic and system constraints should not overshadow the problems relating to the production of such a wing system. Manufacturing tolerances, roughness compatibility with a laminar flow and complexity of the suction system particularly should be borne in mind.

Various programmes are underway in Europe and in the United States, but whatever the position of one programme in relation to the other, the problems existing and the proposed solutions are concordant. To examine this aspect more closely it is necessary to review the problems raised by the development of this particular technology.

**Aerodynamics**

This section deals with configuration and the definition process (design).

Methods must be developed and the transition criteria used in these methods must be validated for high Reynolds numbers (to the order of 30-60). The advantage inherent to these methods is that they will make it possible to considerably reduce the wind tunnel hours. Once these methods have been validated, a more accurate prediction of transition will be possible and an error of a few percent on transition location (5%) will have a significant repercussion on total drag. The methods used can only correctly predict the transition point (effect of suction on longitudinal and cross flow instabilities) if the problem of leading edge contamination has been solved (Figure 12).

**Wind tunnel tests**

The Reynolds number is far from negligible and it is therefore necessary to
use wind tunnels capable of producing a significant Reynolds effect, i.e., highest possible Re.

Currently, many tests are being made on full and half scale models in the large ONERA wind tunnel at Modane (S1 MA) in France. This wind tunnel is wide enough (8 m diameter in the test section) to test large wing sections at high speeds. It will be possible to insert a representative suction system in the leading edge of these large scale models.

The Reynolds numbers obtained in this type of testing are never representative of the Reynolds numbers obtained in flight. Therefore Airbus Industrie has set up a long term laminarity programme and has suggested that calculation codes should be validated on a large scale A320 vertical stabiliser (Figure 13) rather than on a smaller scale wing. In this case the Reynolds number problem would be solved since the A320 half scale fin model achieves a Reynolds number of $24 \times 10^6$ which is exactly that obtained during flight.

Using a cryogenic wind tunnel often makes it possible to obtain Reynolds numbers valid for flight whilst using slightly smaller models. What effect might a pressurised cryogenic wind tunnel have on a thin and perforated surface? Various problems remain unsolved. There are real difficulties in correctly measuring or comparing aerodynamic loads, stability, flutter, and the aircraft’s real performance. Correct prediction of all these parameters in a wind tunnel is not easy; it should be done in the form of 2 and 3D wind tunnel-flight transpositions and comparisons. Wind tunnel tests must allow determination of the aerodynamic characteristics of a laminar aircraft once it has lost its laminarity.

Flight testing

Flight testing should allow validation of all these results, and numerous flight test hours should prove the merits of laminarity. The configuration and definition process and wind tunnel results must be validated.

Performance

Obviously, although cruise performance remains the principle objective, low speed and "off design" performance must nevertheless be studied.

Using a perforated leading edge makes it difficult to envisage the use of a slat which is necessary for low speed performance (Figure 14).

There are two possible solutions:
- a wing with a fixed leading edge but without a high lift system,
- a wing with a fixed leading edge, fitted with a "Kruger" or shield-type system.

In the first case it is not realistic to suggest an aircraft without any lift aug-
mentation system. The increase (30%) in wing surface area, which would make it possible to land with a reasonable approach speed of approximately 70m/ sec is not feasible, since there would be a considerable weight and drag penalty.

In the second case, it is necessary to clearly define the function of the system proposed:

- The "shield" makes it possible to divert the trajectory of any particles (dust, insects, etc.) on landing or at take-off. It can also contain a cleaning system for cleaning the leading edge with a specific fluid.
- The Kruger flap cannot have the same positions as a slat. Performance is different: for example drag on take-off will be higher. It is doubtful whether it is possible to achieve acceptable CLmax levels for landing. The complexity of the various Kruger systems currently in use such as variable camber and fixed Kruger flaps will exclude their use since they lead to a decrease in performance and to resistance by the users.

**Anti-icing system**

Anti-icing is a prime concern in the development of a laminar wing system. Currently, the anti-icing systems most commonly used on commercial aircraft function on a basis of very hot air (200°C) circulating within the slats (Figure 15). Using a fixed and porous leading edge raises several problems. Possible solutions would be blowing hot air through suction holes.

Is it possible, however, to envisage a multi-function system (suction and fan-blower) where the suction system must obviously be entirely sealed? This immediately raises the following questions or remarks:

- Can the system function in two ways, without having to be made far more complex?
- Can the system function correctly at a temperature of 200°C and over?
- The system must function correctly during all flight phases (climb, descent, cruise).
- Concerning the use of a shield during take-off and landing, the system could be equipped with a special fluid. This system would not work, however, at high speeds and a further system for cruise conditions would have to be developed.
- The use of an integrated anti-icing system has never been envisaged with Kruger flaps.

In general, anti-icing remains an acute problem. Research is under way to define, study and test a new anti-icing system for laminarity application. The anti-icing problem cannot be shelved and it will be taken into account during the A320 fin flight tests, if possible.

**Wing/Engine interference**

The development of large diameter engines, such as the GEnx, requires an engine installation system different to that used for a CF6 or PW4000-type engine. The nacelle could be at the wing level and this could suppress the high lift system in the affected wing section, it would also lead to a different pressure distribution pattern. Insect contamination on the wings could become a very real problem and a special anti-icing and cleaning system would have to be developed for this particular part of the wings.

**Laminar technology feasibility**

Development of such laminar flow technology requires a great deal of investigation:

- **Validation of tools**
  - transition = ?

- **Application**
  - upper surface
  - both surfaces

- **Leading edge devices:**
  - Kruger flap
  - slat
  - suction effect on CLmax

- **Suction power installation**
  - engine
  - auxiliary engine or APU
  - engine location (wing, fuselage?)

- **Technology problems**
  - suction system
  - leading edge contamination
  - cleaning
  - deicing
  - anti icing
  - surface quality
  - manufacture of suitable leading edge

- **Maintenance problems**
  - dirt
  - cleaning (water, soap)
  - degradation
  - etc...

- **Certification**
  - fuel reserves
  - suction system failure in flight
  - etc...

- **Real DOC for airlines?**

Many flight tests would be necessary before this technology could be introduced to the airlines. The real advantages must be made clear to future users, not only in terms of fuel burn reduction but taking into account problems such as:

- system reliability, in order to have...
minimum number of incidents during flight,
• reduced complexity, to ensure minimum maintenance,
• normal operational use without any special attention during take-off or landing in cloudy conditions or in rainy weather,
• laminar flow control during flight, in order to correctly assess the quantities of fuel necessary for the flight,
• the high production costs of such a wing system. For example, to have a laminar upper surface it must not have any roughness greater than 0.1 mm,
• wing reinforcement problems, above each engine, and problems caused by adding performance systems such as strakes, vortex generators, fences, etc.,
• finally, the laminar parts of the wing would have to be very clearly defined.

Surely the only possible part of the wing system will be the upper surface. For aerodynamic reasons (contamination due to fuselage boundary layer, high deviation, C, etc.) the inboard part of the wing (from the fuselage to the first engine) might also be excluded.

An industrial prototype using the HLFC concept should be rapidly launched by manufacturers. Solving the technical problems and achieving reasonable costs constitutes a challenge: manufacturers will have to convince the airworthiness authorities of the feasibility of the project before approaching the airlines.

**FRICHT DRAG DURING CRUISE**

A further method of significantly reducing friction drag has been studied at length by all the manufacturers. Separate programmes have been launched concerning two different technologies: Riblets and Large Eddy Break-up (LEBU) devices.

**Riblets**

In order to modify the sub-layer of a boundary layer, the effect of very fine grooves (a few microns high) has been tested in wind tunnels (Figure 16). Results showed a significant reduction of between 7 and 8% (Figure 17), but since the cause is not fully known, riblet studies have remained at the experimental stage.

Airbus Industrie’s programme comprises several stages:
• transonic pod test at Onera-CERT in Toulouse (France),
• wind tunnel tests on A320 model at Modane,
• flight tests on the A320 aircraft 1,
• industrialisation studies.

Two parameters are used to define the riblet size: H' and S'. The value H/S = 1 is apparently most productive (Figure 18). In all cases the most optimistic
The transonic pod tests were performed in the ONERA-CERT "T2" cryogenic wind tunnel. The pod was fitted with internal scales. A 3M riblet film was applied to the cylindrical part of the model.

T2 tests confirmed the improved results and showed a reduction in drag even when the riblet direction was different to that of the flow (\( \Phi < 20^\circ \)).

The wind tunnel tests on the A320 model (February 1989) showed an identical skin friction reduction at Mach 0.78. The wind tunnel Reynolds number obtained during the tests was lower than that obtained during flight. A full A320 model was used at a scale of 1:11. With 70% of the surface covered in riblet film a saving of 1.5% was noted at cruise Mach number.

The flight tests on the first A320 aircraft were performed in October 1989. Approximately 75% of the wetted surface was covered in 3M riblet film. Size (H*, S*) being optimised for cruise flight at M = 0.78 but tests at different Mach numbers and Cf were performed. The aircraft was fitted with boundary layer rakes on the fuselage, a wake rake and a moving system for measuring the boundary layer at the forward part of the fuselage during flight. The numerous measurements during flight were made with and without riblet film.

The objectives of this programme were to assess the real saving in fuel consumption, the reduction in local friction drag (Cf), and to identify the effect of riblets on buffet onset and on C\( _f \) max. Results obtained during flight indicate an average saving of 1.5% (Figure 19).

Several problems must be solved before a proposal is made to the airlines:
- Visual detection of cracks in the structure and skin.
- Areas where the film is in contact with hydraulic fluid must be accurately defined as it rapidly causes deterioration of both paint and film.
- Acceptable installation and removal times must be achieved. Airbus Industrie and 3M have defined a technique that has cut down 3M's first assessment by ten. Concerning removal, aquastripping seems the most suitable technique.
- Aircraft maintenance frequently involves minor repairs and it will probably be necessary during maintenance to remove a few square metres of film.
- It is necessary to thoroughly understand the behaviour of the riblet geometry over a six year period which represents the time between repainting aircraft.

Tests are currently being performed on the A320 which has not been repainted and cleaned for nearly three years and still has its riblet film unaffected (Figure 20). Although the aerodynamic advantage procured by riblets has been clearly demonstrated, a few problems relating to industrialization remain to be solved. A programme of industrial assessment is currently underway and should make it possible to conclude on the utility of this technology.

An application of film restricted to the wing upper surface, horizontal stabilizer and the upper part of the fuselage (i.e. above the windows) would lead to a saving of approximately 1% in fuel burn on a long haul type aircraft.

**Large eddy break up**

Large eddy break up (LEBU) depends on small profiles distributed in the boundary layer. These structures act on any large eddies. Studies have been initiated to determine their optimum height (H) in the boundary layer.

Results of studies performed at CEAT-Poitiers (France) show an optimum with H/S = 0.8 (Figure 21). Results obtained at transonic flow (Mach 0.75) show a saving of the order of 15% on the local Cf. This reduction, however, is highly limited over a short time (30 seconds).

The conclusions drawn from these LEBU studies are not very optimistic taking into account LEBU drag support and the necessary structure. The overall aerodynamic breakdown does not show any significant saving. Installation of these profiles on a fuselage would lead to many problems: flight vibrations and optimisation at the various coefficient of lift encountered.

**Figure 19**

In October 1989 riblet flight testing in Airbus during a two-week period determined the overall fuel-burn reduction

| Boundary layer rakes for local measurements | Skin friction reduction confirmed (approximately -6%) |
| Engines equipped for global measurement | Fuel-burn saving confirmed (approximately -1.5%) |

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Figure 20
Riblet evaluation on the A320 aircraft number 1

After nearly three years in flight on the A320, the aerodynamic and material characteristics of the riblet film have been evaluated directly on the aircraft.

For example: geometry and size profile are compared with reference profile every six months.

Figure 21
LEBU results in transonic flow

![Diagram showing LEBU results in transonic flow with Mach number and CD x 100 graphs.](image)

Mach number:
- 0.7
- 0.72
- 0.75
- 0.8
Many solutions have been put forward to reduce an aircraft's overall drag. The potential for reducing drag is real but demonstration of the saving in terms of fuel burn is very difficult.

Manufacturers’ prime concerns are to correctly predict aircraft drag levels in flight and to examine all possibilities for reducing drag.

It should not be forgotten that calculation methods cannot currently predict drag accurately. With atmospheric wind tunnels (such as the Modane S1) results must be corrected in order to predict the (L/D) efficiency of the aircraft when cruising.

It is in the manufacturers’ interests to promote ideas and check their validity. Research should concentrate on achieving significant reductions in drag (e.g. the HLFC concept). They should take particular care to assess fuel consumption savings and eventual penalties concerning weight, cost, etc. linked to such technologies, bearing in mind that in order to convince airlines, the extra cost of the aircraft must often be recovered during the first or second year of operation.

The following difficulties can still be stated:
- Although results may be shown in 2D tests, transposing them to 3D flow is often uncertain and sometimes impossible today.
- Industrialisation of certain concepts often seems highly problematical.
- The overall analysis (e.g. in the case of LEBU) often shows that reduction of the friction coefficient implies penalties in other areas such as higher drag (friction drag) or greater weight.

Drag reduction remains however a permanent concern for manufacturers whose aim is to offer the best possible product to the airlines.
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<td>ZHURICH</td>
<td>41 (1) 8102838</td>
<td>41 (1) 8127727</td>
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The scope for drag reduction was far greater seventy years ago than it is now. In 1921 the first large passenger aeroplanes were just beginning to appear. Designed by an Italian called Caproni to carry one hundred passengers, the giant “Capronissime” flying boat had three sets of triple wings, in tandem.

This solution to the problem of adequate lift was described as “bold and reasonable because the virtues of wings in tandem are a long way from being exhausted”. The eight engines were installed on the forward and aft centre wings in a mixed tractor pusher arrangement. Unfortunately, this Caproni aircraft only made one flight. However, in recent years, small tandem-wing aircraft have been flown successfully.

Wing span: 98 ft 5 in (30 m),
Length: 77 ft (23.5 m),
Height: 30 ft (9.1 m),
Weight: 55,100 lbs (26,000kg),
Power: 8 Liberty, V-12 liquid cooled engines

The Caproni Ca 60 Transaero flying boat on Lake Maggiore in Italy in 1921.
The bulk of passenger aircraft flying today owe their origins to designs from the early sixties.

When it comes to replacing them, there's just one real alternative.

Airbus Industrie have the only all new family of aircraft available.

Since the conception of the world's first twin-aisle twin, the A300, Airbus Industrie have led the way in civil aviation technology bringing ever greater efficiency and higher profits to the world's airlines.

And now the Airbus family of aircraft have the world's route networks covered, there's only one question left unanswered.

Which Airbus?