getting **hands-on experience** with aerodynamic deterioration

A PERFORMANCE AUDIT VIEW

AIRBUS

Flight Operations Support - Customer Services Directorate

GETTING HANDS-ON EXPERIENCE

WITH AERODYNAMIC DETERIORATION

A PERFORMANCE AUDIT VIEW

Preamble

Today's tough competitive environment forces airlines to reduce their operational costs in every facet of their business. All ways and means to achieve this goal have to be rationally envisaged, safety being of course the prime factor in any airline operation. A wide variety of different aspects have to be taken into consideration in this process, such as airline economics, airline management, flight operations, maintenance management, technical condition of aircraft.

The purpose of this document is to examine the influence of the latter with respect to aerodynamic deterioration.

The manufacturer does his utmost from the development onwards by foreseeing all potential deteriorations and by adopting less sensitive designs. This goes on in service life by continuous development and modification programmes, the aim being to keep the aircraft in good condition as efficiently as possible. Unfortunately, in the life of an aircraft, normal or abnormal degradations are likely to occur. An aircraft is normally expected to have its drag increased by up to 2 % within five years. Indeed, many aerodynamic elements may suffer extra drag and their cumulative effect can result in a significative fuel consumption increase and associated fuel bill.

Systematically adopting corrective measures to repair these items inevitably leads to excessive maintenance costs. Therefore, the effect of aerodynamic deteriorations has to be traded against the estimated maintenance cost to establish whether it is cost-effective to carry out corrective measures or not. Cost-benefit analyses are thus the only practical way to approach the topic of aerodynamic deterioration, at least when keeping an eye on both operational efficiency and technical realism.

Airbus has carried out numerous performance audits in cooperation with airlines which, implicitly, have made a very useful contribution in preparing this brochure. The information contained in this brochure aims to help you adapt your maintenance programs, balancing out financial aspects, such as increased fuel consumption, against maintenance costs. It should enable operators determine whether corrective actions are financially pertinent, despite short-term maintenance costs. Considerable longer term expense may thus be avoided at relatively low cost. And strategic maintenance actions rather than detailed, dispersed and costly repair jobs may be more easily decided upon as well as better justified.

Would you please sent your comments and remarks to the following contact point at AIRBUS. These will be taken into account in the following issues to be edited.

AIRBUS

Flight Operations Support & Line Assistance
Customer Services Directorate
1, Rond Point Maurice Bellonte, BP 33
31707 BLAGNAC Cedex - FRANCE
TELEX AIRBU 530526E
SITA TLSBI7X
TELEFAX 33/(0)5 61 93 29 68 or 33/(0)5 61 93 44 65

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1. GENERAL

1.1 Aerodynamic deterioration

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

1.1.1 Sensitivity classification

The fuel burn penalty caused by drag-inducing items is largely dependent upon the location and extent of the problem; different areas of the airframe are more or are less sensitive to alterations in their optimum aerodynamic smoothness. Bearing this in mind, a zonal classification can be established for drag sensitivity over the whole aircraft.
«Zone 1 » areas require high aerodynamic smoothness because they are endowed with high local flow velocities and very thin boundary layers which are very sensitive to small local disturbances. «Zone 3» areas are much less sensitive because of lower flow velocities and thicker boundary layers, and disturbances on these parts of the airframe do not produce high aerodynamic resistance to the airflow. Also, the transition from laminar to turbulent boundary layers having occurred earlier, «Zone 3» is less sensitive to aerodynamic irregularities or excrescences. Finally, «Zone 2» areas represent an average between these two extremes.

The localisation of Zones 1, 2 and 3 for Airbus Industrie aircraft are shown in the following figures (A300, A310, A320, A330, A340) on pages 2-6.

1.1.2 Fuel penalty calculation

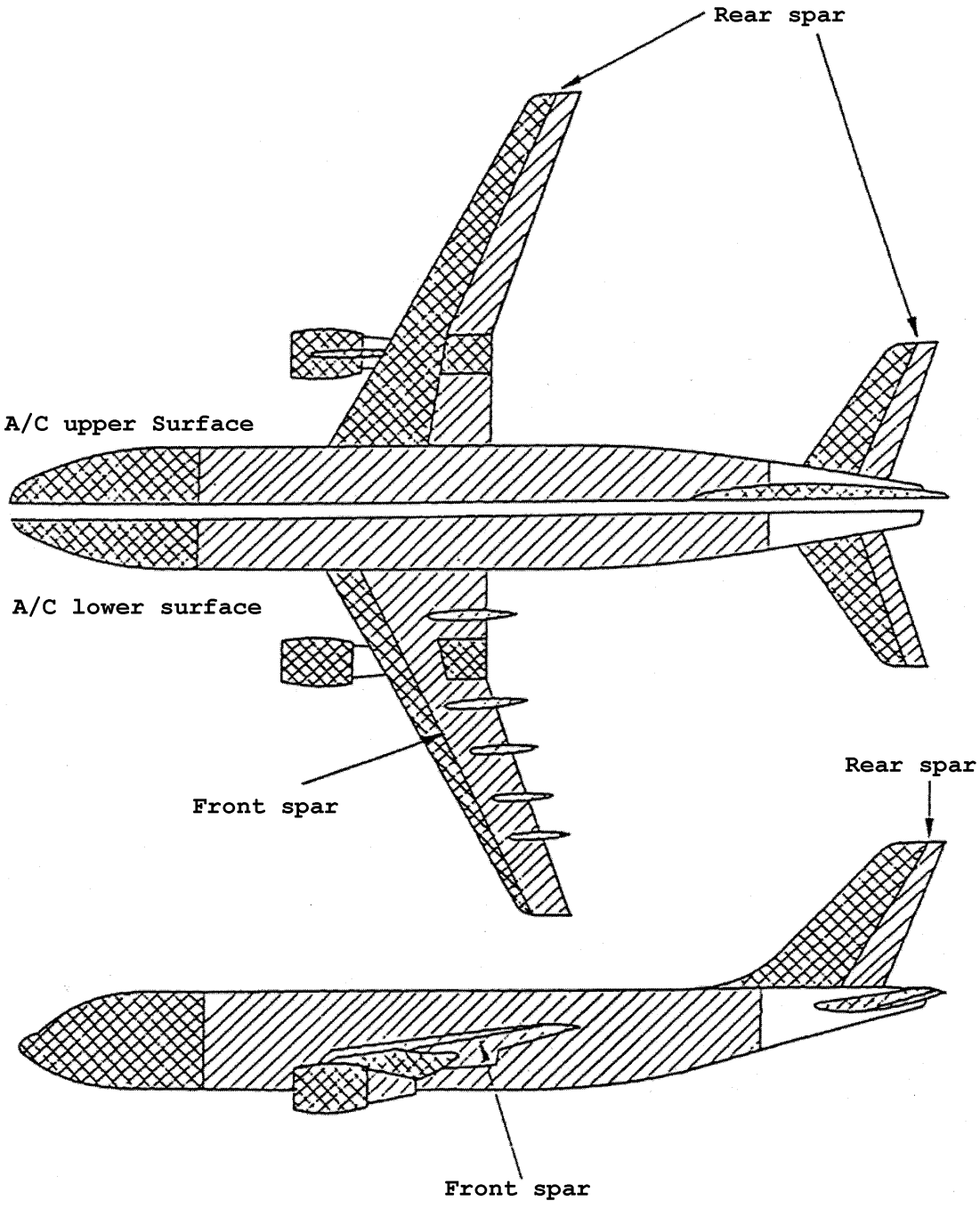
It is possible to determine drag increases, generated by particular items with wind-tunnel measurements or analytical techniques. The drag increase is then converted into terms of increased fuel burn - in US gallons per year per aircraft - but the reader must keep in mind that values given correspond to an aircraft which is in accordance with specific assumptions. These assumptions refer to each type of aircraft of the three Airbus families and include annual flight hours based on airline statistics.

The drag increase can also be expressed in US$ per year per aircraft, the fuel price being estimated at **US$0.60 per gallon**. Since calculation assumptions may vary significantly among individual operators, tables giving a corrective factor - to apply to the fuel penalty to be derived from the operator's annual flight hours - will be given for each type of aircraft.

A300

DEGREE OF SMOOTHNESS

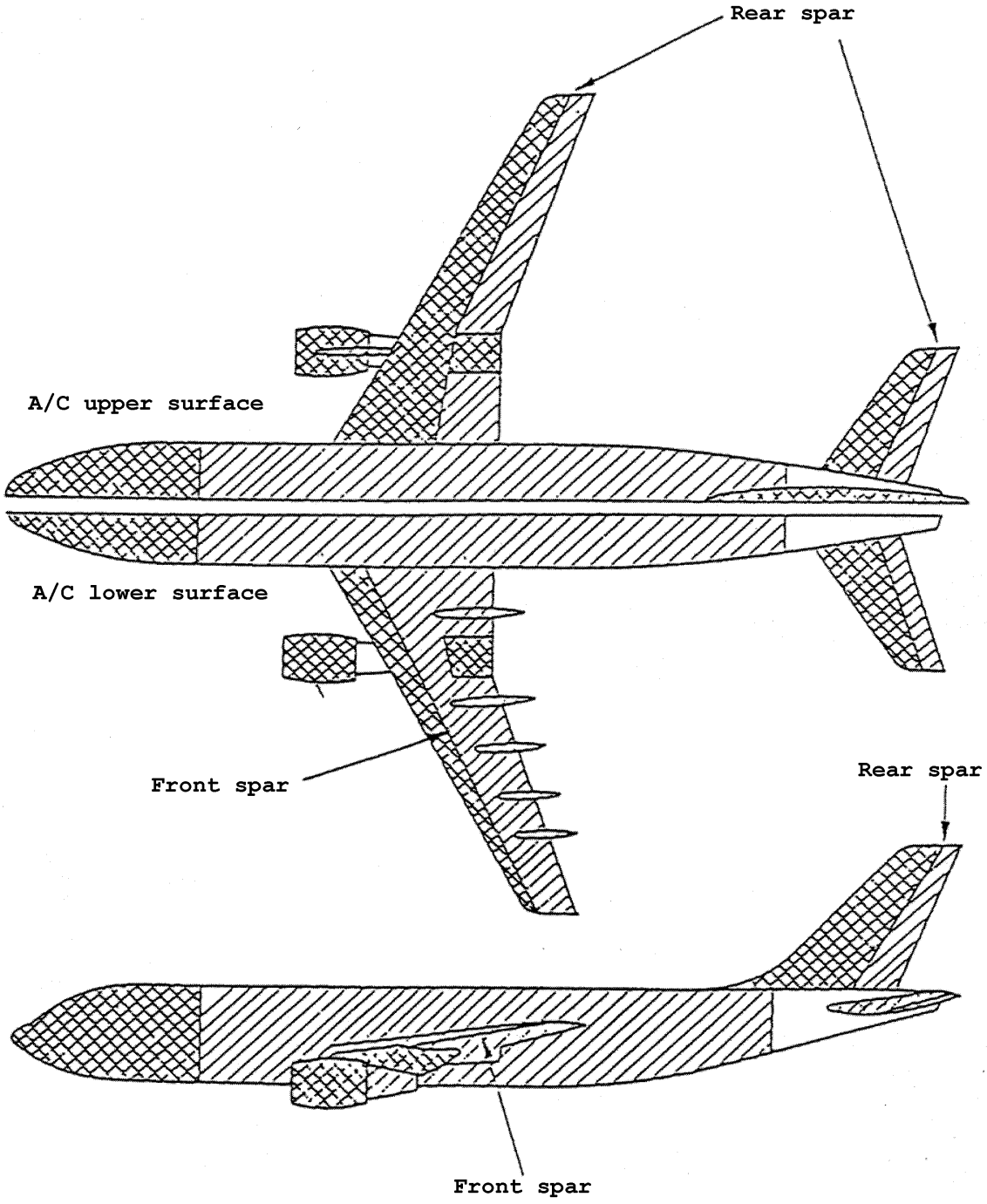
	ZONE 1	High Sensitivity
	ZONE 2	Medium Sensitivity
	ZONE 3	Low Sensitivity



A310

DEGREE OF SMOOTHNESS

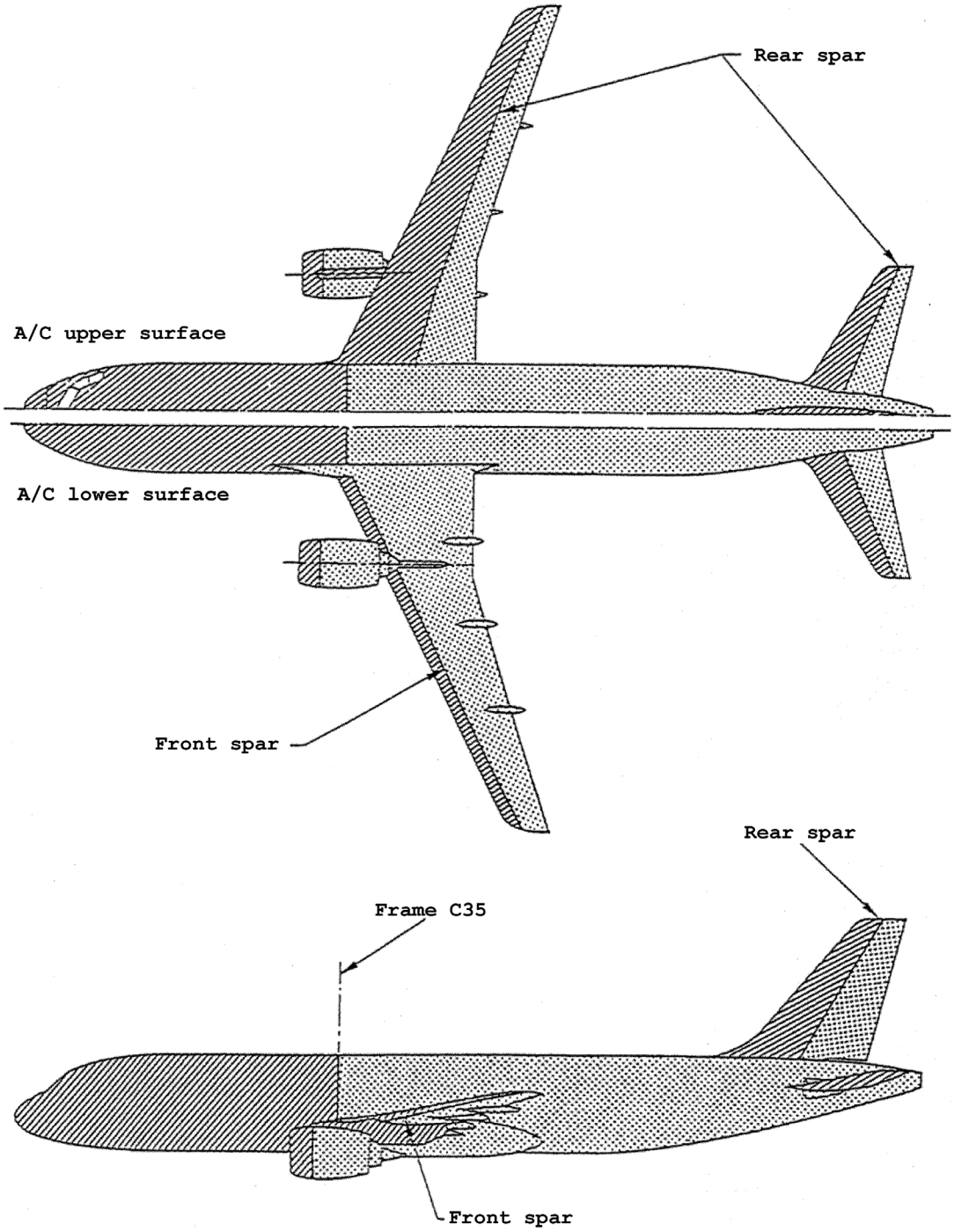
	ZONE 1	High Sensitivity
	ZONE 2	Medium Sensitivity
	ZONE 3	Low Sensitivity



A320

DEGREE OF SMOOTHNESS

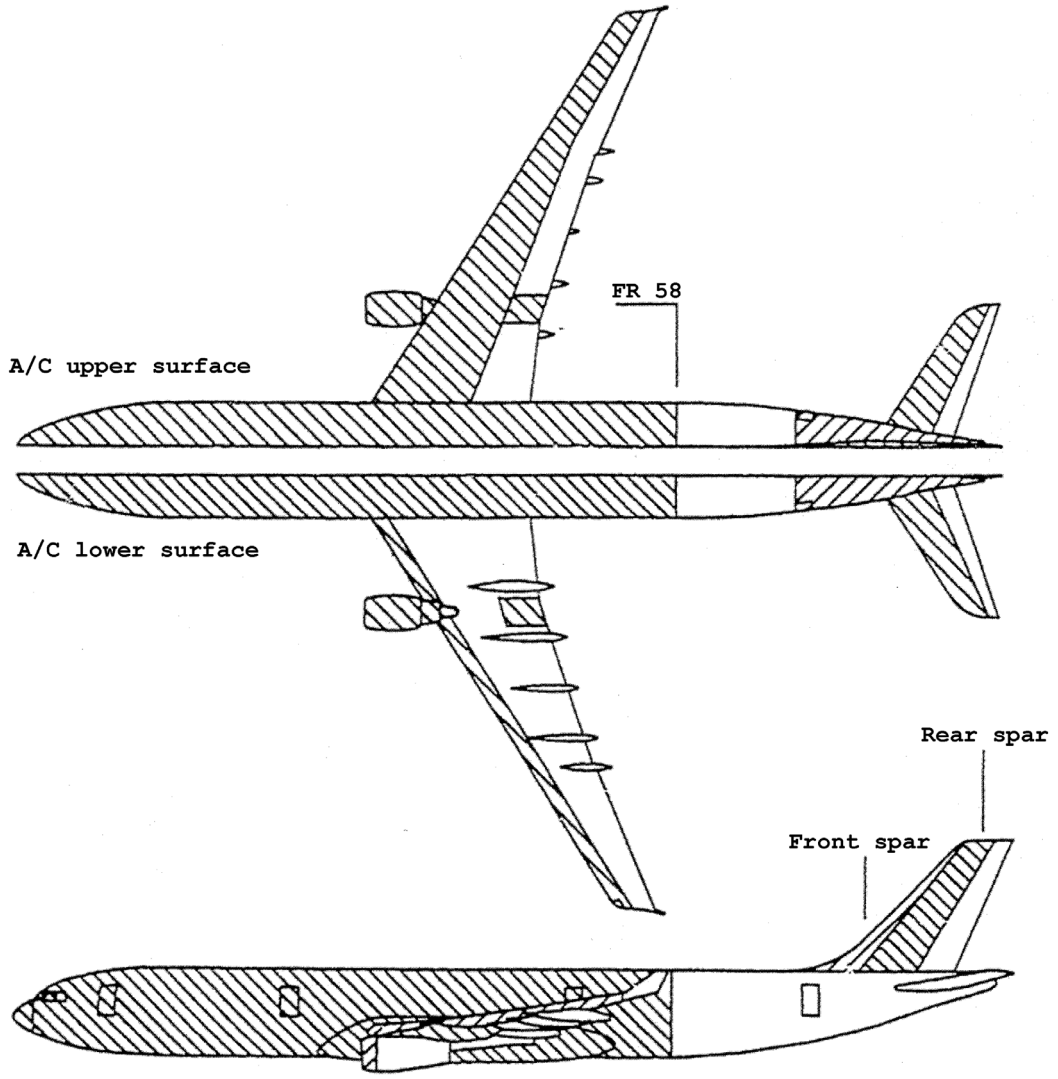
//////	ZONE 1	High Sensitivity
	ZONE 2	Medium Sensitivity



A330

DEGREE OF SMOOTHNESS

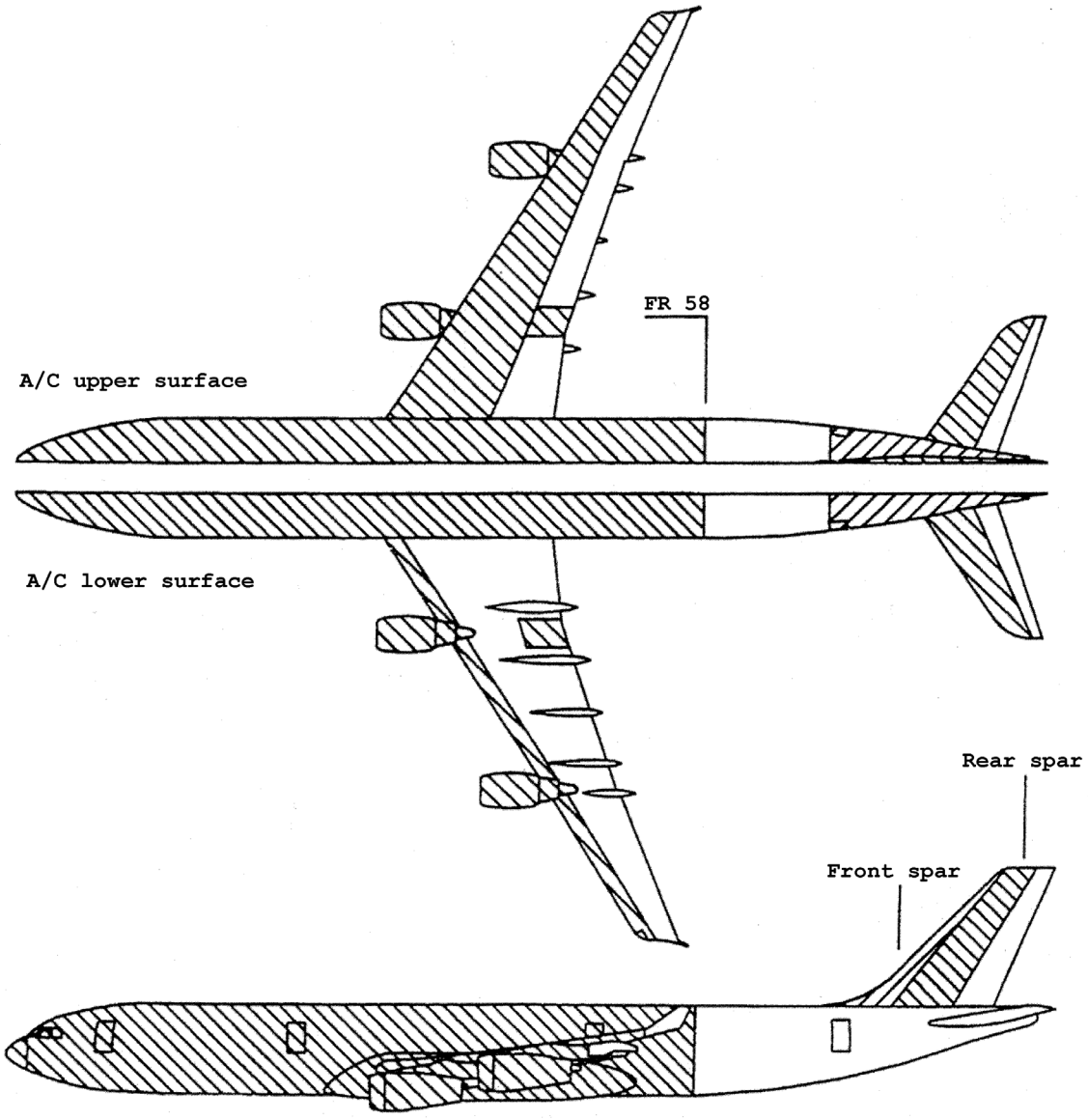
	ZONE 1	High Sensitivity
	ZONE 2	Medium Sensitivity
	ZONE 3	Low Sensitivity



A340

DEGREE OF SMOOTHNESS

	ZONE 1	High Sensitivity
	ZONE 2	Medium Sensitivity
	ZONE 3	Low Sensitivity



1.2 Airframe maintenance

For a specific corrective task, manhours required can significantly vary from one airline to another, and from one type of repair to another. The calculation method adopted in this document is simply an estimation partly based on measurements. These tasks should have been carried out assuming a regularly maintained aircraft, operated under normal conditions and with an average daily utilisation, having maintenance/corrective actions carried out in a hangar with good environmental conditions. All necessary standard and special tools, as well as ground support equipment, skilled maintenance personnel and appropriate maintenance documentation should also be available. The values presented below (men and manhours) are based on these assumptions and are intended to reflect operational reality as closely as possible.

Total maintenance costs, for both on-aircraft and shop tasks, include overhead and burden costs for maintenance planning, engineering orders, safety equipment, facilities and supervision. An acceptable rate per manhour covering all these aspects is US$50. Serving as a benchmark, this value corresponds to an average cost covering skilled personnel working.

1.3 Adapted maintenance programme

As stated above, the degradations that are likely to occur stem from two main sources (excluding incidents or handling) : either mechanical wear or corrective actions which have not been properly executed. Although ill-considered or superficial repair may have negligible effect on performance, some tasks have to be carried out with special care, given their positive impact on fuel consumption.

As mentioned before, despite the efforts of maintenance organisations and manufacturers, deterioration can occur. It may have significant effects on consumption in spite of having only a slight influence on drag. One way to determine these effects is to use the Aircraft Performance Monitoring (APM) software. This programme calculates deviations in Specific Range and, to some extent, helps to determine how much these discrepancies stem from engine degradation and how much from a lack of aerodynamic cleanliness. Inherently, the program does not really differentiate between apparent and real drag.

For instance, higher drag may be concluded from APM results but could, in fact, reflect lower thrust at N1 (or EPR). Also bleed leaks can affect apparent aerodynamic deterioration through N1 deviations by biasing the N1/thrust relationship if they are not accounted for. For these reasons, values given by the APM software have to be considered with great care.

Nevertheless, it can trigger an alarm at a predetermined loss of Specific Range if in relation to the initial aircraft drag condition, and an unscheduled check could be launched to detect the type and location of any drag rise. This unscheduled check could be like a line check walkaround associated with an overwing in-flight check observing and photographing control surfaces, preferably by means of a telephoto or zoom lens. The association of both types of check constitutes an «Aerodynamic Inspection». The items to be observed are reviewed and listed in the following tables. This Aerodynamic Inspection, which would take only a short time to perform, should be done by skilled personnel as for example aerodynamics or performance engineers, able to interpret secondary effects (e.g. leakages)

and to determine the corresponding deviations (as well as being able to conduct performance audits).

When both the type and extent of the deterioration are known, the following tables could be used to determine what should be repaired and what may be ignored, for financial reasons. Repair times should be scheduled during nights-time periods, time permitting, otherwise the task has to be included in a scheduled check.

The Aircraft Performance Monitoring software has the advantage of potentially triggering an Aerodynamic Inspection just when it seems to be needed, thus avoiding pointless inspection.

If the APM software is not used, the Aerodynamic Inspection could be scheduled, for instance, at the occasion of a «C check».

Although this approach may confirm discrepancies, not all might be identified. In this case direct measurements in the suspected area should be made, such as prescribed in the Aircraft Maintenance Manual. This second way is more expensive but it may offer better drag reduction results.

In a third stage, if the drag reduction seems insufficient, the airline may then ask Airbus for a Performance Audit.

These three approaches should help any airline to alleviate excessive fuel consumption.

2. LISTED ITEMS

2. LISTED ITEMS

These lists are not exhaustive; they simply correspond to the main airframe deteriorations or misrigged surfaces.

The purpose of the following paragraphs is to give a fuel penalty / maintenance cost comparison and to propose an existing or suggested method in order to ensure that there are no discrepancies.

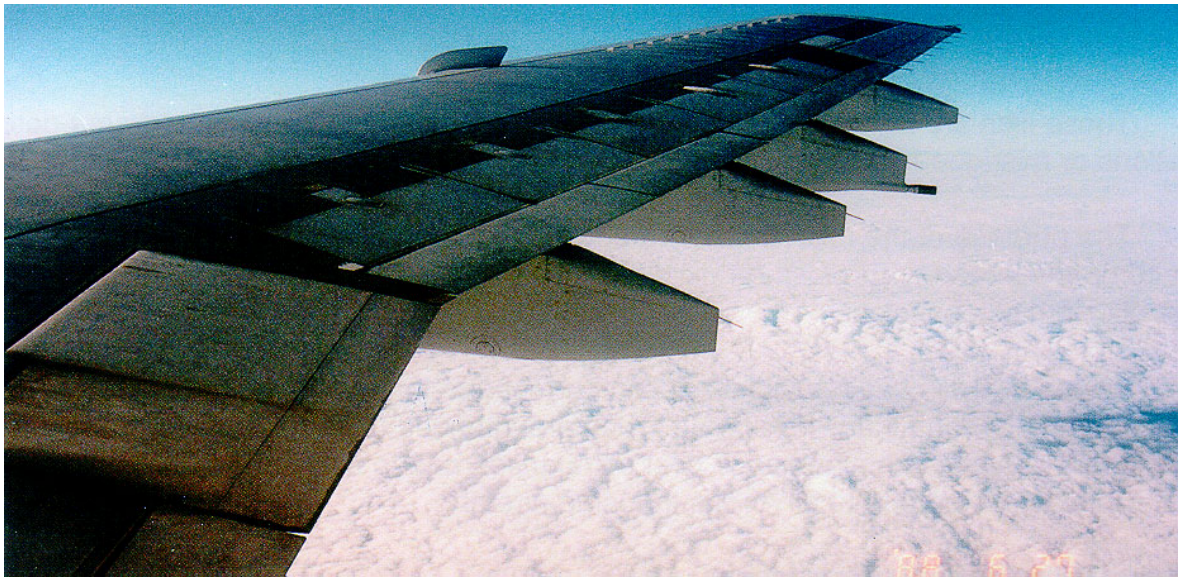
Values given in this particular section correspond to the smaller fuel penalties applicable to all Airbus Industrie aircraft. They are intended to make the reader more sensitive to fuel penalties / maintenance cost comparison and to sort out a few general conclusions which pertain to all Airbus Industrie aircraft.

2.1 Misrigging of control surfaces

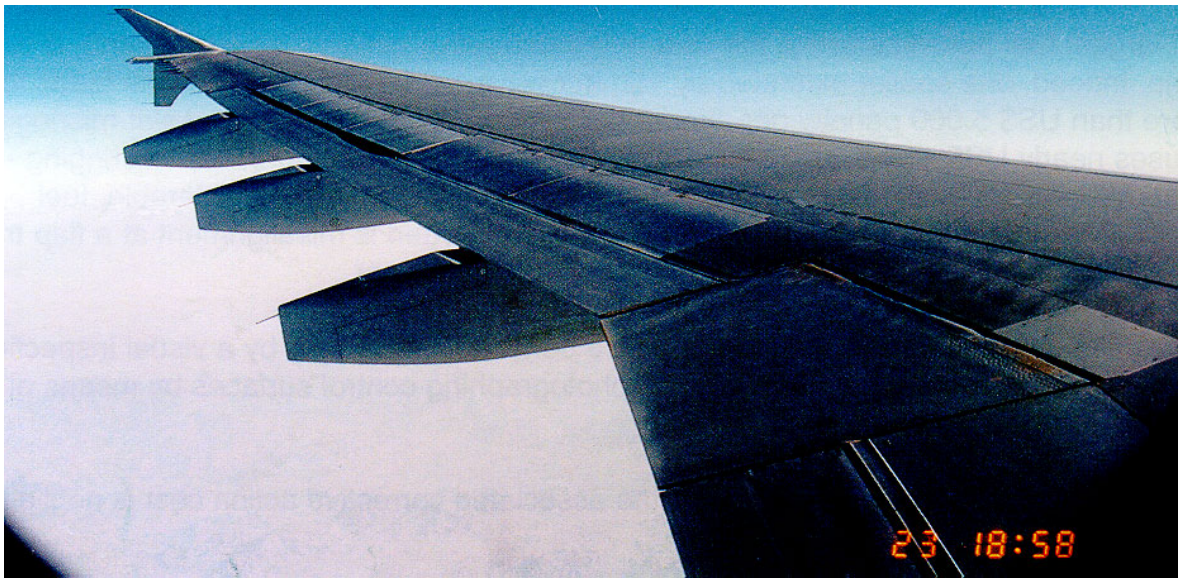
These items correspond to specific control surfaces misrigging. They incur one of the largest fuel penalties, while the cost of the corrective actions, by comparison, is negligible. Indeed, one spoiler extended by 15mm over a 1 metre spanwise length leads to more than US$ 5,000 penalty per aircraft per year. Similarly, an outboard slat misrigging causes nearly US$ 11,000 penalty per aircraft per year. Furthermore, flap misrigging - or especially rudder misrigging - can lead to a slightly lower, but still considerable, fuel penalty. Another sensitive item which is generally forgotten is misalignment at a flap track fairing which may cost nearly US$ 1,000 per aircraft per year.

The Aerodynamic Inspection could be done in flight, simply by a visual inspection from the passenger compartment and by photographing control surfaces by means of a telephoto or zoom lens.

For a misrigged control surface, the associated corrective action cost is negligible and should indeed be undertaken.

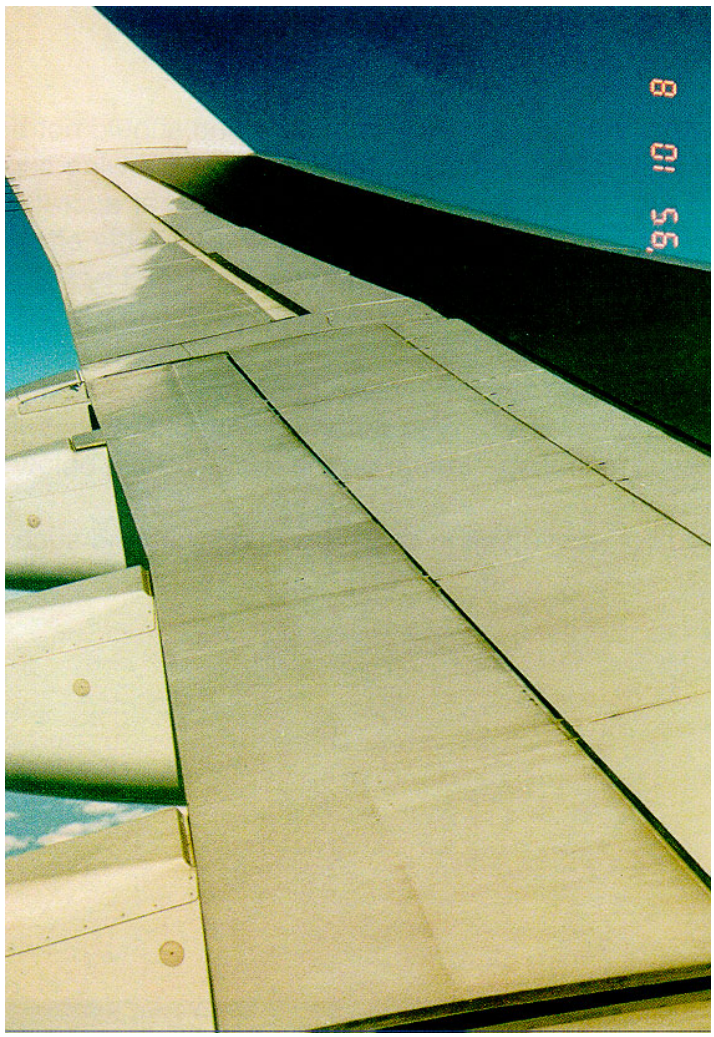


A300 wing

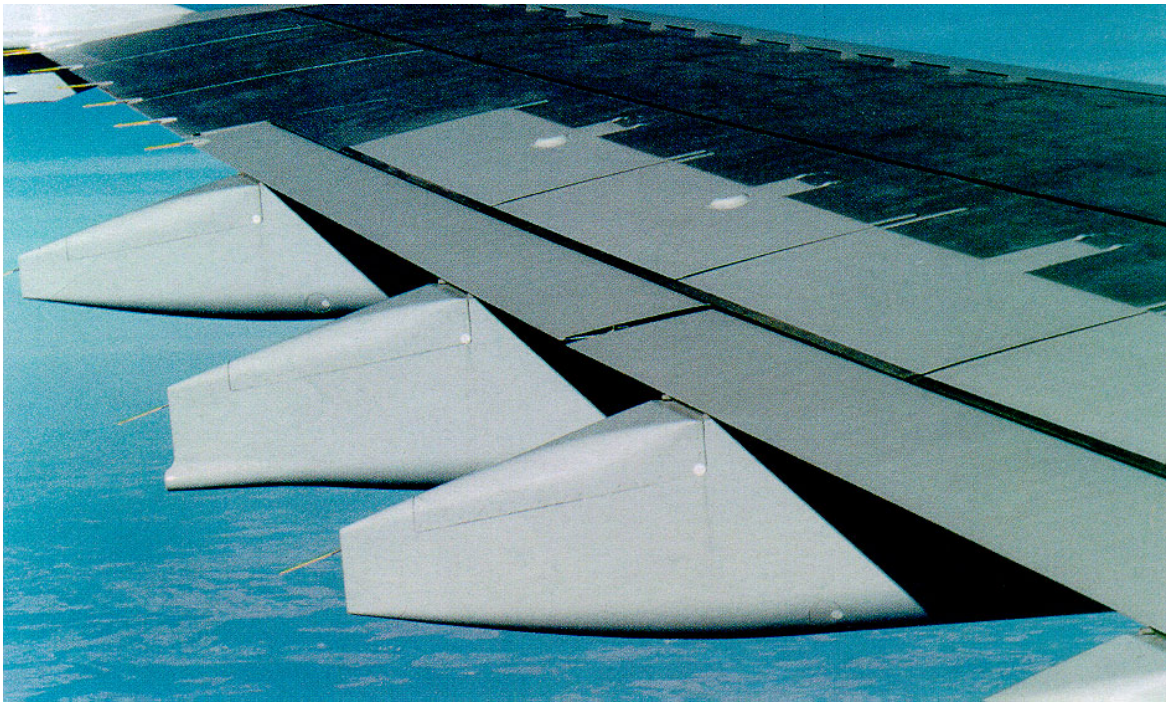


A310 wing

A320 wing



A340 wing



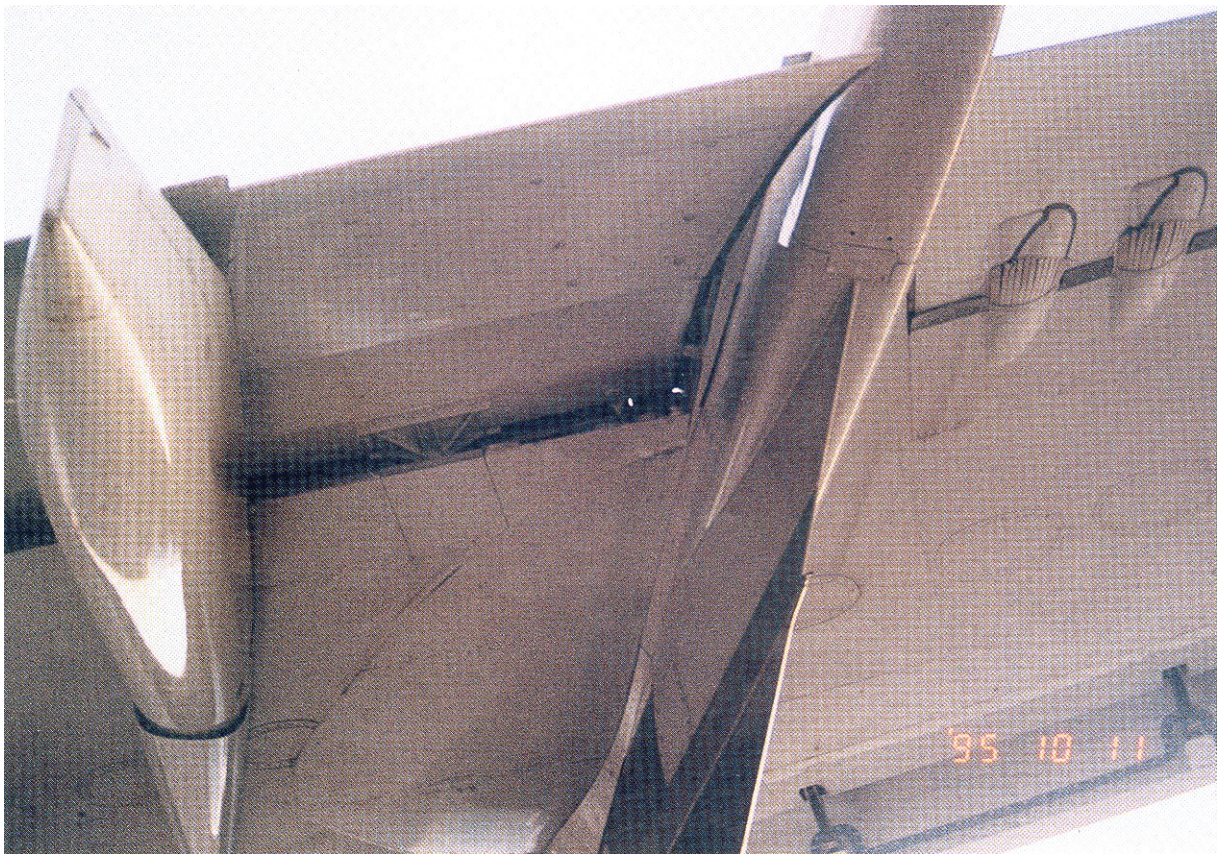
A300/600 wing

2.2 Absence of seals on movable sections

Seals on movable sections are very important and should not be forgotten. The spanwise slat seals are mandatory for the optimisation of the wing supercritical airfoil. One metre of missing seal incurs a penalty of US$ 2,300 per aircraft per year. The chordwise flap seal, which may seem to have a rather negligible effect, causes more than US$ 3,000 extra cost per aircraft per year. However, the worst penalty would result from a missing fairing and rubber seal at the fin/fuselage junction (US$ 3,500).

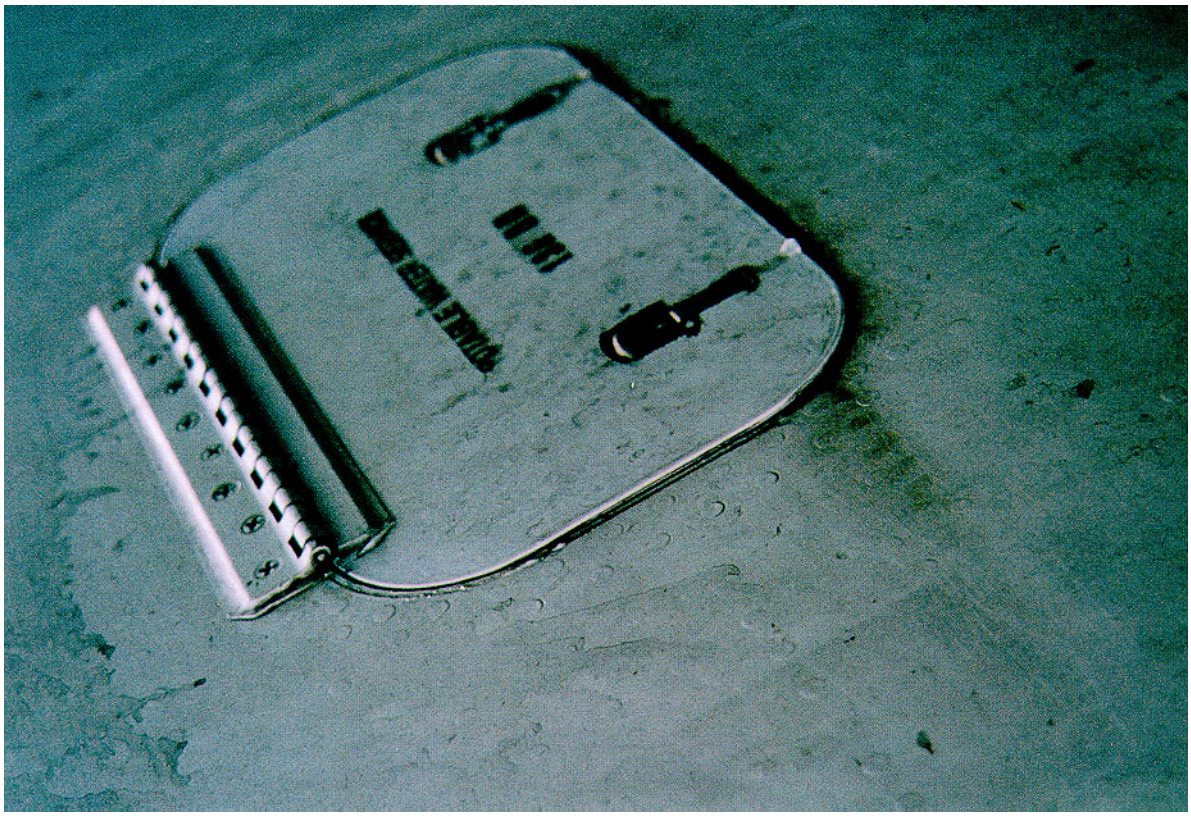
The check can be done from the ground during the Aerodynamic Inspection, preferably with extended control surfaces. With retracted control surfaces, the same check could be done by analysing leakage traces on the wing surface below the seals.

The associated corrective action costs are negligible and such action should be scheduled.



2.3 Missing parts

Missing parts are given in the Configuration Deviation List showing missing parts which must be replaced as soon as possible. The tables shown on pages 41, 91 and 128, provides adequate motivation to shorten this delay.



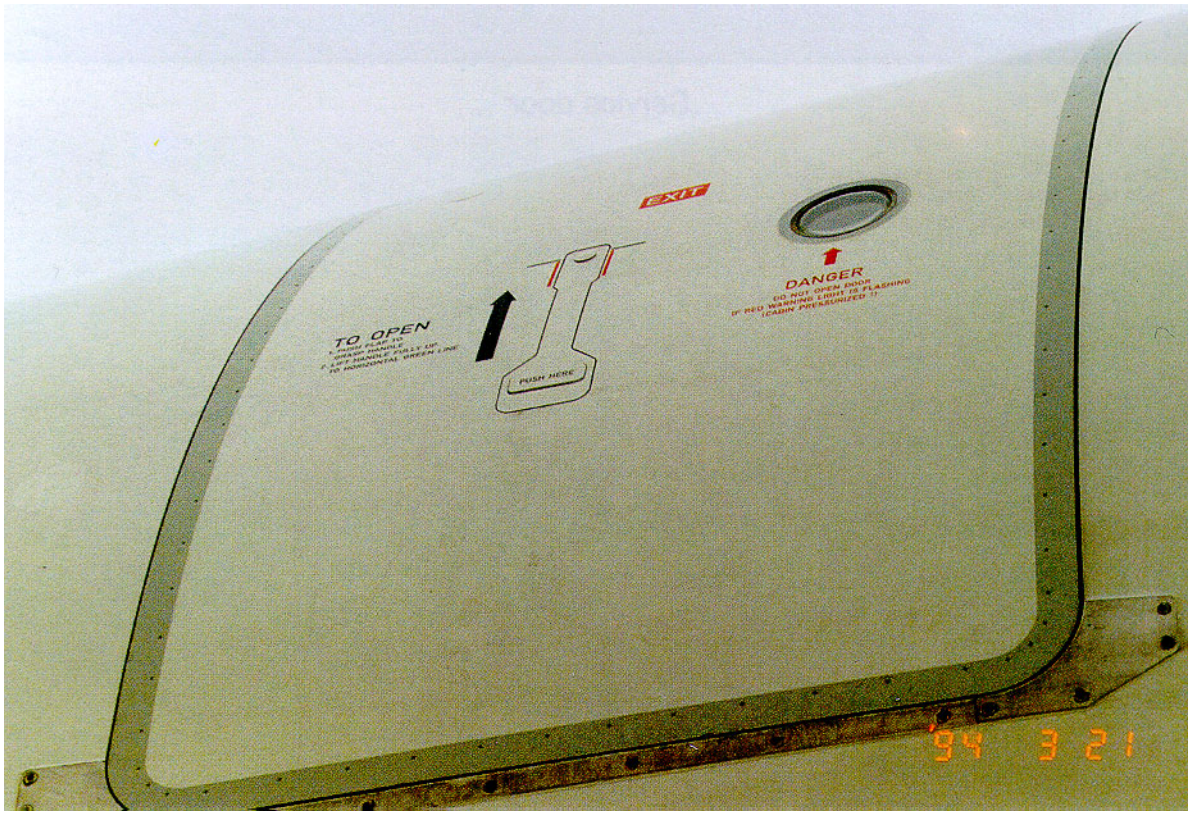
Service door

2.4 Mismatched doors

A step on the forward fuselage surface is much more penalising than one on the rear. Misalignment of forward doors must be monitored very carefully; a 10mm forward cargo door step imposes a US$ 2,300 annual penalty, although the associated corrective action costs US$ 650.

During the Aerodynamic Inspection, the door can be checked by standing under it and observing the line where it meets the fuselage. Due to pressurisation, the door must be slightly out of flush with the fuselage. In other words, the door must be 2-3 mm inside the fuselage when checked on the ground.

The decision - to repair or not - is not easy, knowing that an estimated rigging cost could be much higher, especially if insufficiently skilled personnel are available. The decision is a matter of judgement by each operator.



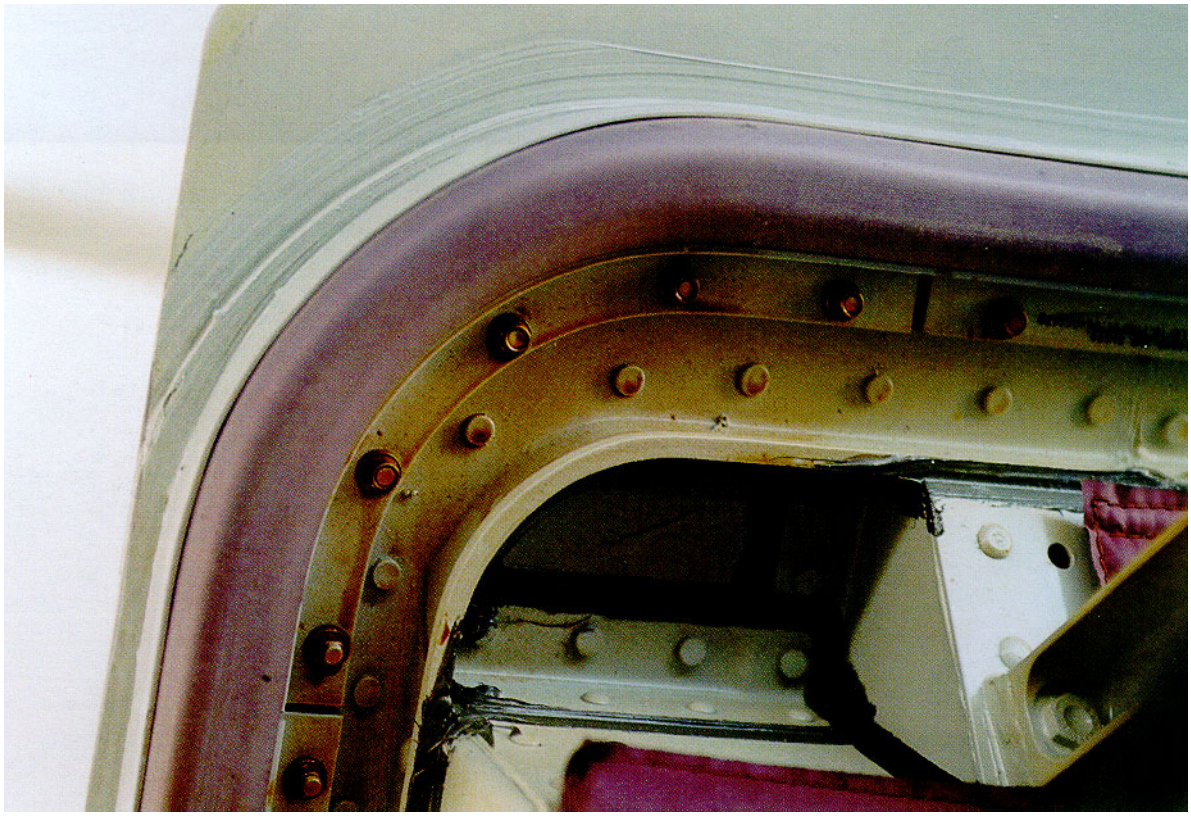
Passenger door

2.5 Missing door seal section

A missing door seal section has two effects: it disturbs the external flow and causes a slight leakage which has to be compensated for by an increase in engine compressor air bleed. In addition to the fuel penalty, a stress-provoking low-frequency whistling sound is audible in the cabin which could possibly annoy passengers.

Preferably, the inspection should be done with the door opened, looking for damaged sections of the seal. With a closed door, the same verification could be done simply by analysing dirt traces on the fuselage.

Since this leakage may increase with time, even if corrective actions are quite expensive, this work should be implemented to remove the risk of further deterioration which would lead to the aircraft being grounded eventually.

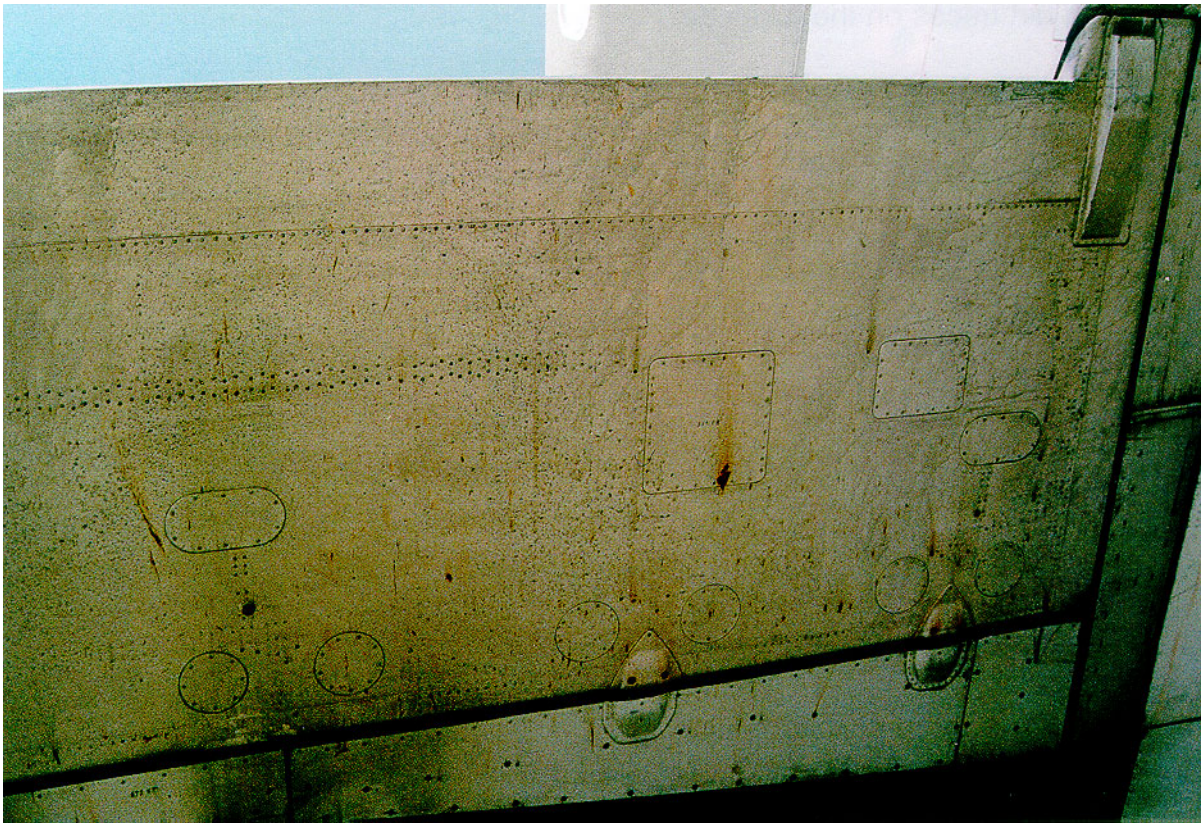


Passenger door seal

2.6 Surface deterioration

2.6.1 Skin roughness

Surface deterioration can lead to significant fuel penalties, especially if the skin is rough or dirty. For a complete aircraft - in the worst case - the penalty can be as high as US$ 60,000 per aircraft per year. Another serious penalty would certainly be on the airline's commercial image!

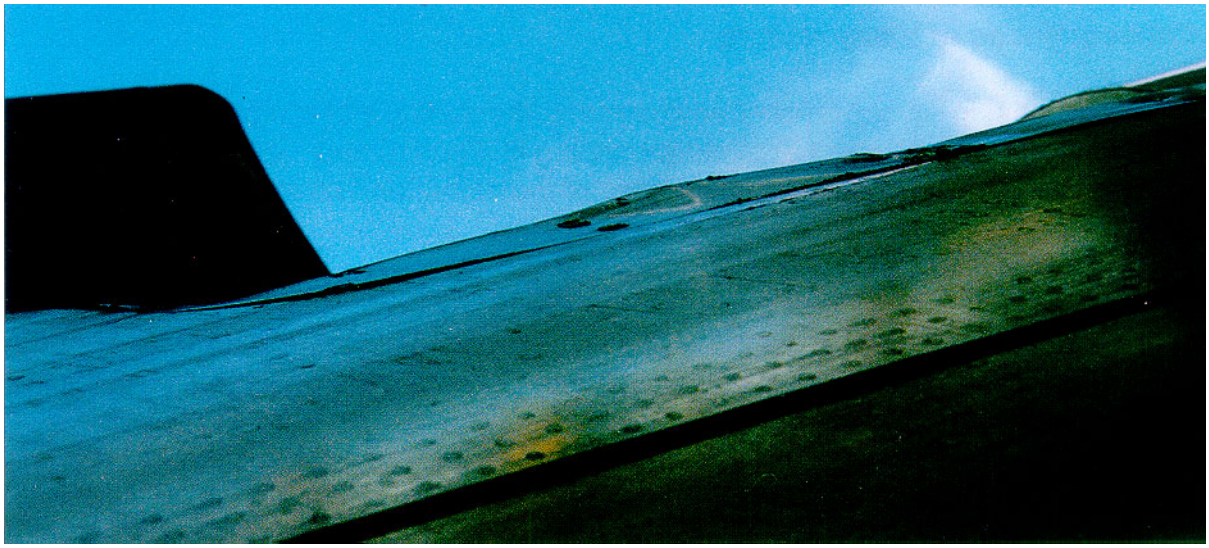


Flap

2.6.2 Skin dents

Simple dents also cause some fuel penalty which are not costly in terms of fuel consumption (US$ 100 per aircraft per year in the worst case) but are very expensive to repair. If the dent is within the Structural Repair Manual tolerances, no action is necessary for purely aerodynamic reasons.

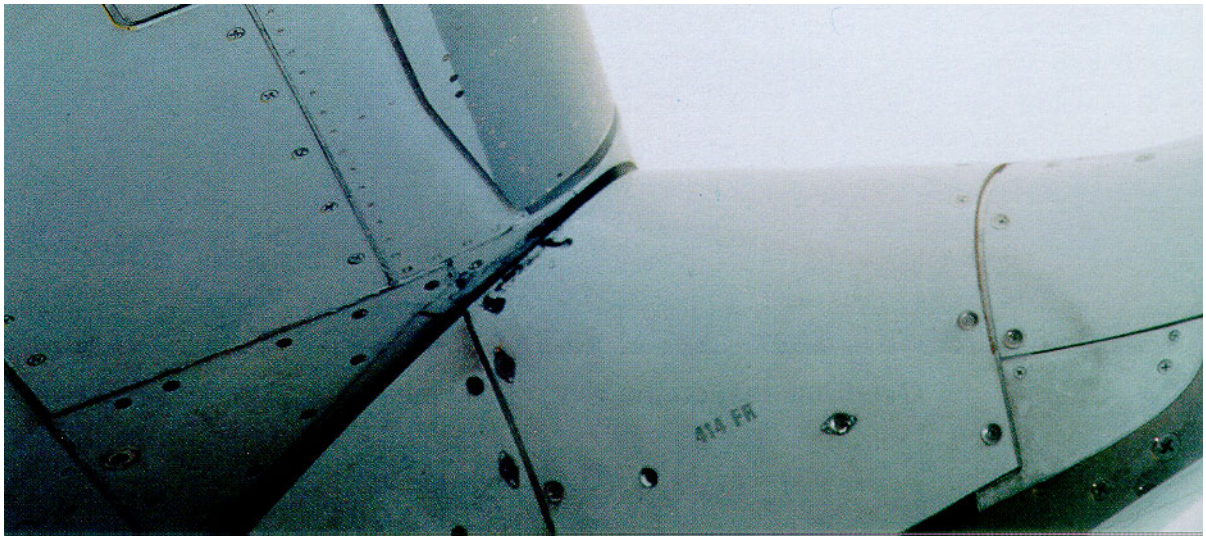
With repeated «loaders' assaults», scuff plates are frequently dented and generally present a step, generating high fuel penalties, but corrective actions are not particularly time-consuming.



Dented scuff plate

2.6.3 Unfilled butt joint gap

Unfilled butt joint gaps in aircraft skins are not very expensive in terms of excess fuel consumption (US$22 per aircraft per year in the worst case).



Missing seal on the wing / pylon junction

2.6.4 Conclusion

Manhours for structural repairs must be determined with great care because significant differences exist, mainly depending upon the exact location of the deterioration.

All these discrepancies can be observed very easily from the ground during the Aerodynamic Inspection.

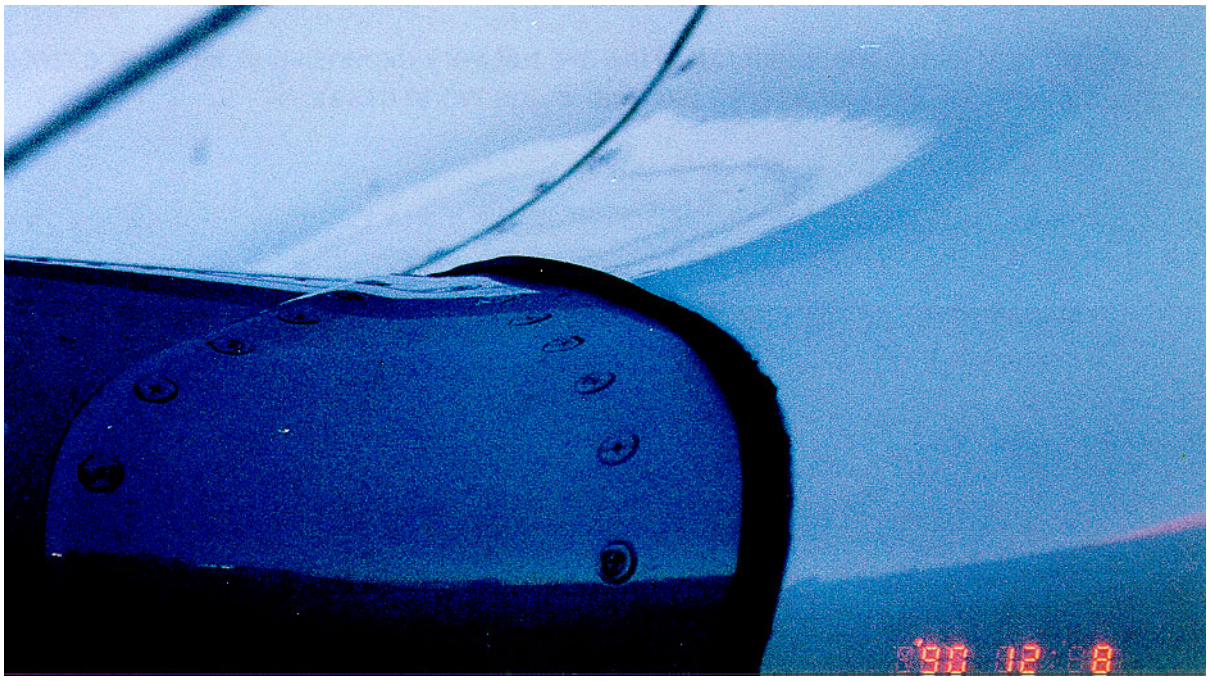
The decision whether or not to rectify a loss of surface smoothness is not easy and is a matter of judgement by each operator.

2.7 Consequences of hasty repairs

Sometimes, in an operational environment, the purpose of a repair is simply to keep the aircraft in service and to avoid grounding it. Repairs may have been done without taking into account the consequences of increased fuel consumption.

2.7.1 Overfilled butt joint gap

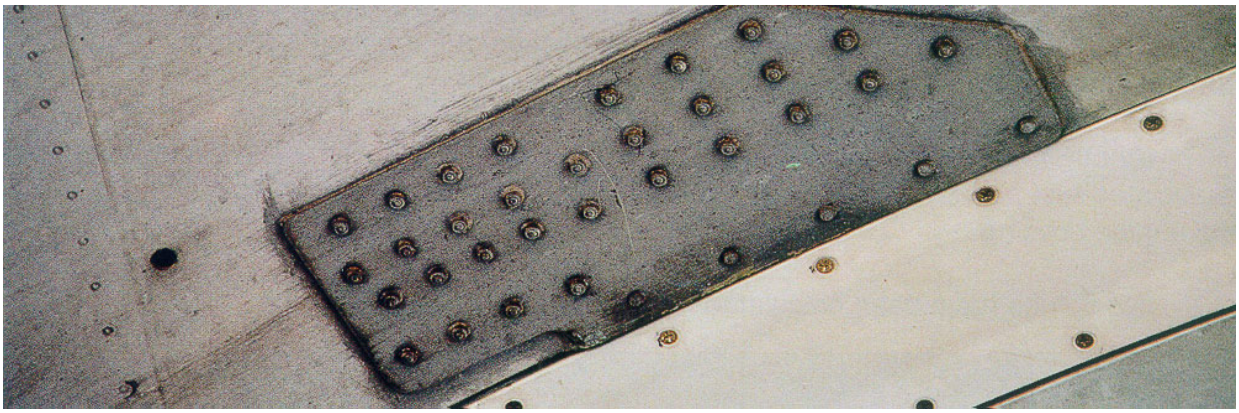
If a butt joint gap is overfilled, the penalty can be significant on the wing upper surface (US$330). The tables, corresponding to each aircraft type, show that a repair which is not properly carried out can lead to a heavier fuel penalty than existed prior to the repair (from US$14 per aircraft per year for an unfilled butt joint gap to US$500 for an overfilled gap on the upperwing in the sensitive «Zone 1»).



Overfilled seal on the wing / belly fairing junction

2.7.2 External patches

In the same way, external patches induce more drag, especially on the wing upper surface (US$640). It is normally difficult to replace an external patch by an internal one, but if access has already been gained during an inspection, installing an internal patch could be preferable, since it also has less impact on an airline's commercial image.



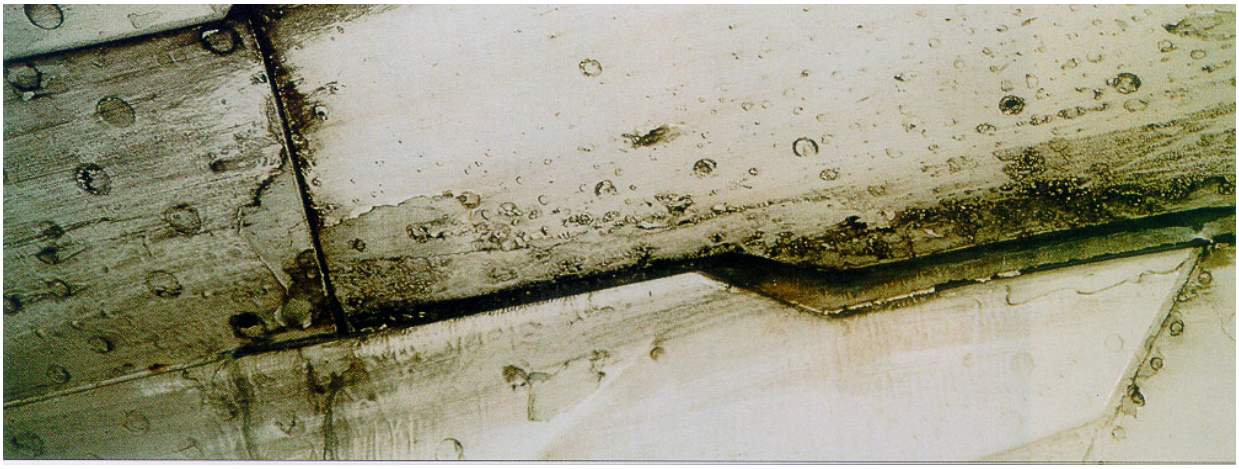
External patches on the fuselage

2.7.3 Paint peeling

On the other hand, for visually improving the commercial image, some fleets are often hastily repainted without bothering to properly prepare the surface. Additional paint layers cause increased aircraft weight and the surface is less smooth due to paint steps. Over a short time, paint may peel, with dramatic drag effects, and severe risk of corrosion.

In order to prevent paint problems, proper preparation has to be carried out before any refresher coat is applied.

Manhours for painting have also to be determined with great care because ground time due to paint drying has much more effect on aircraft operation than the simple manhour cost by itself.



Belly fairing

2.7.4 Conclusion

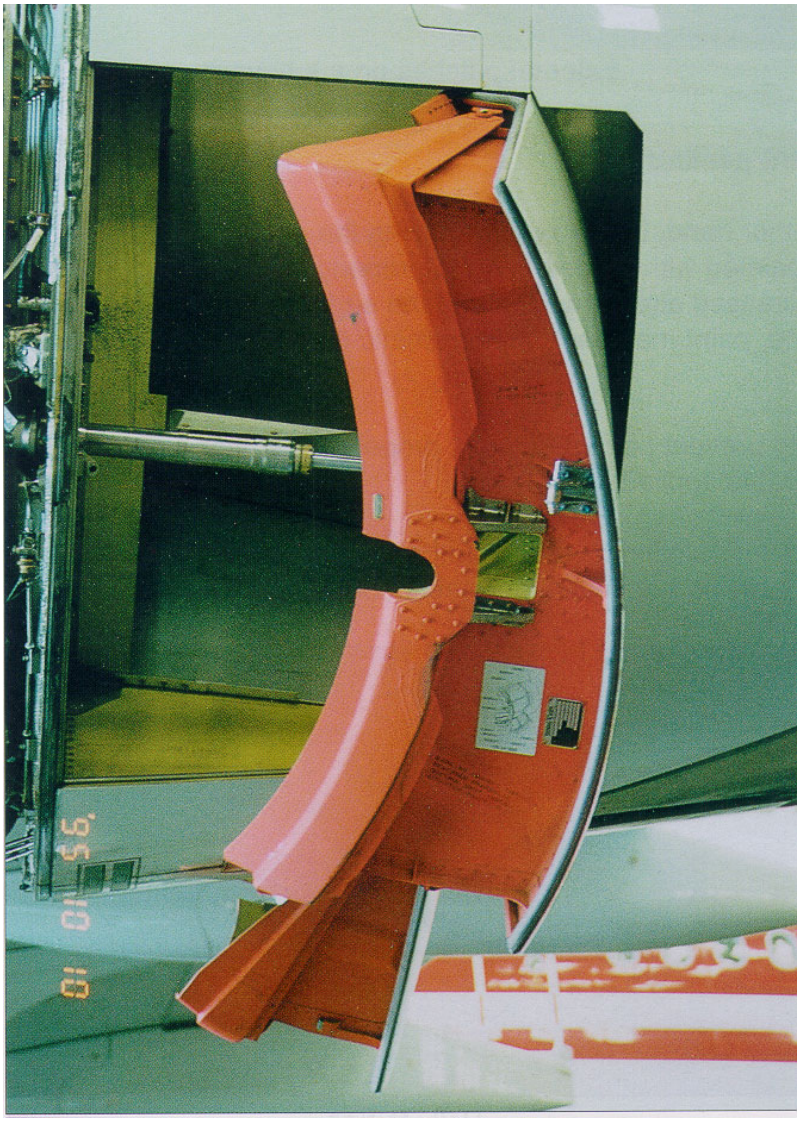
The Aerodynamic Inspection will identify all of these items, but the decision whether to repair or not will, perhaps, not be an obvious one.

2.8 Engine cowling

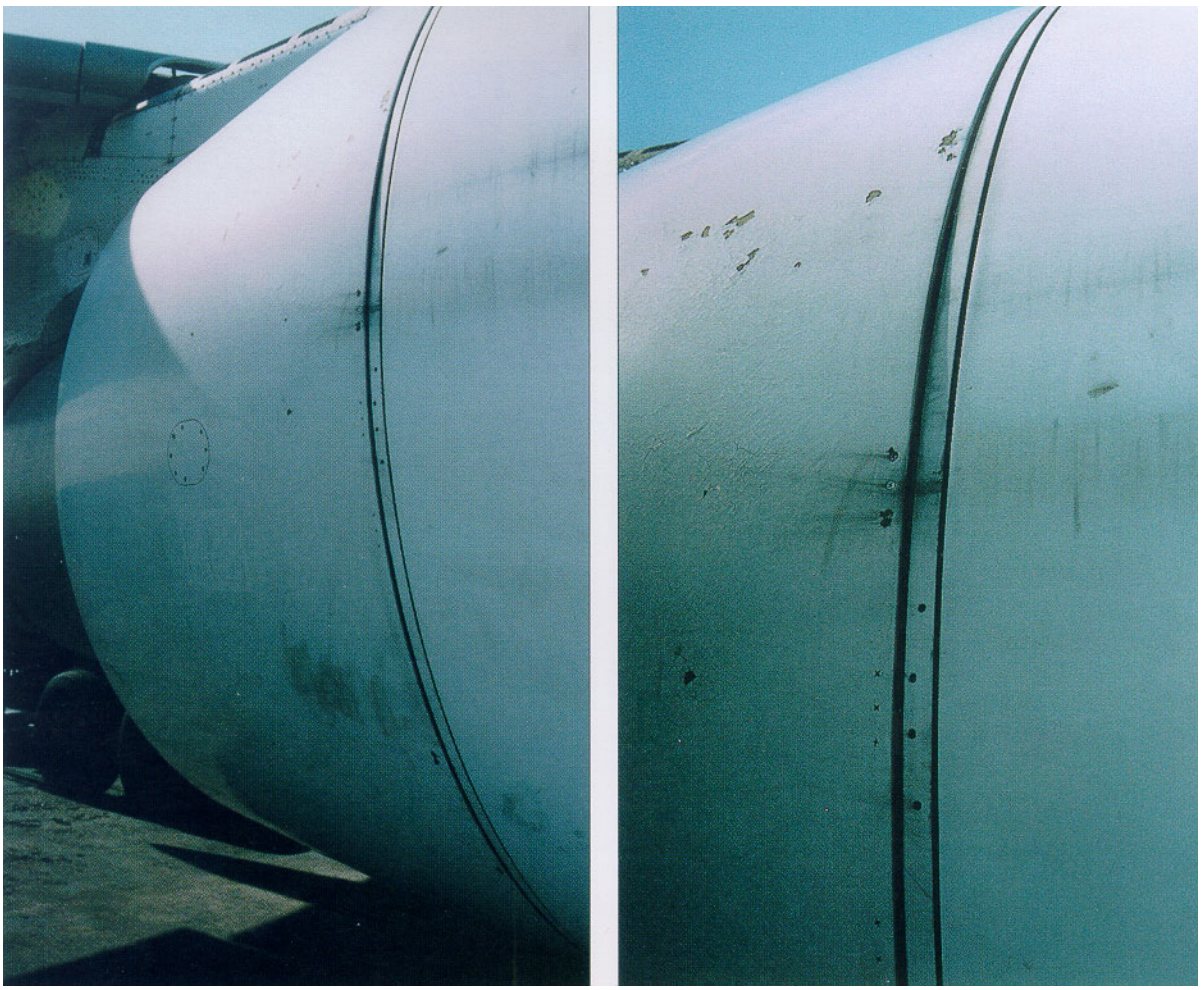
The engine cowling, due to its location in a very sensitive zone, has to be observed with great care during the Aerodynamic Inspection. All surface discrepancies incur considerable drag.

Another item, which is less obvious because it is hidden, is reverser air bleed. The associated fuel penalty is very large. Nevertheless, it can be observed by leakages on the engine cowling.

No values have been calculated for this penalty.

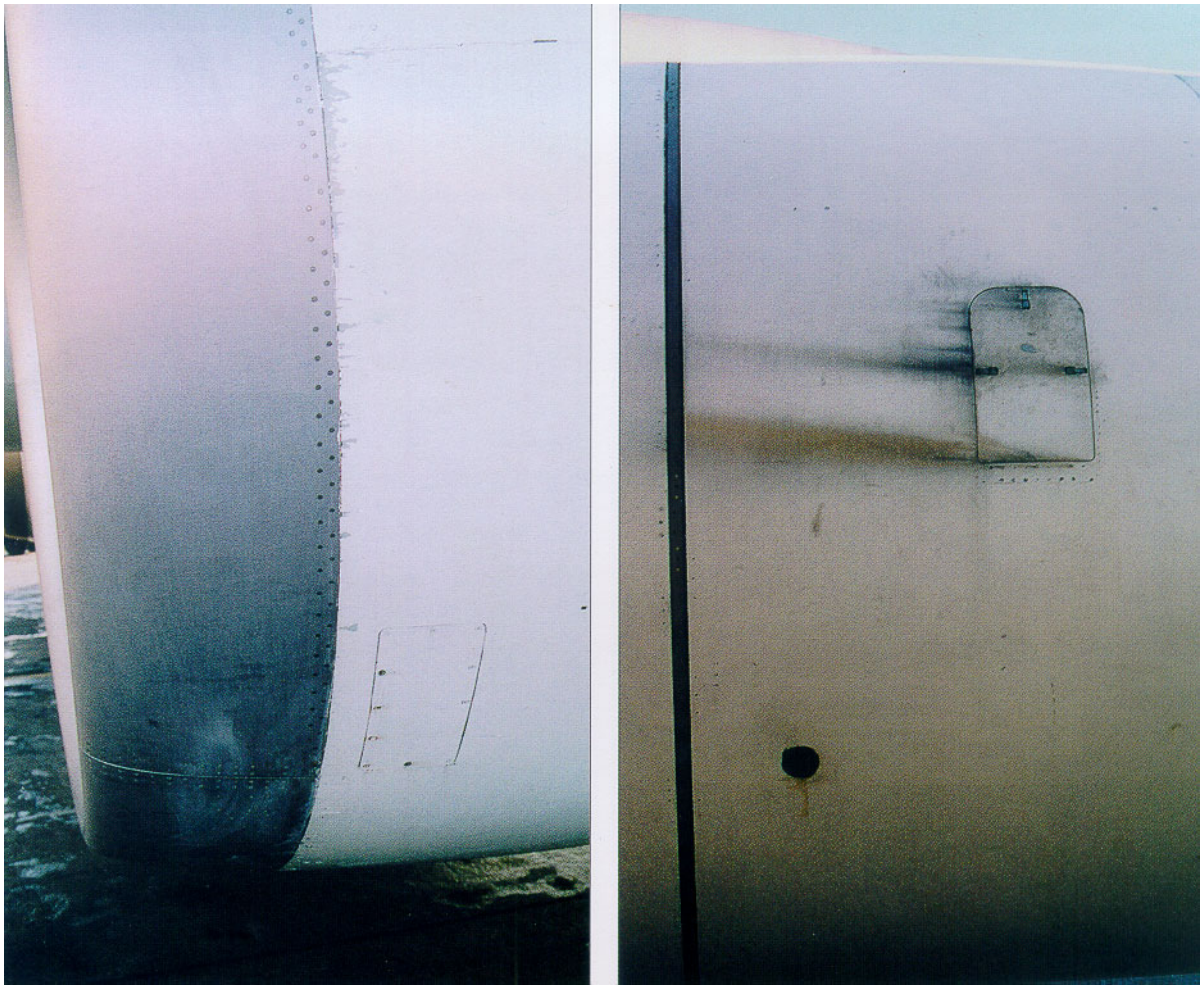


Reverser door seal

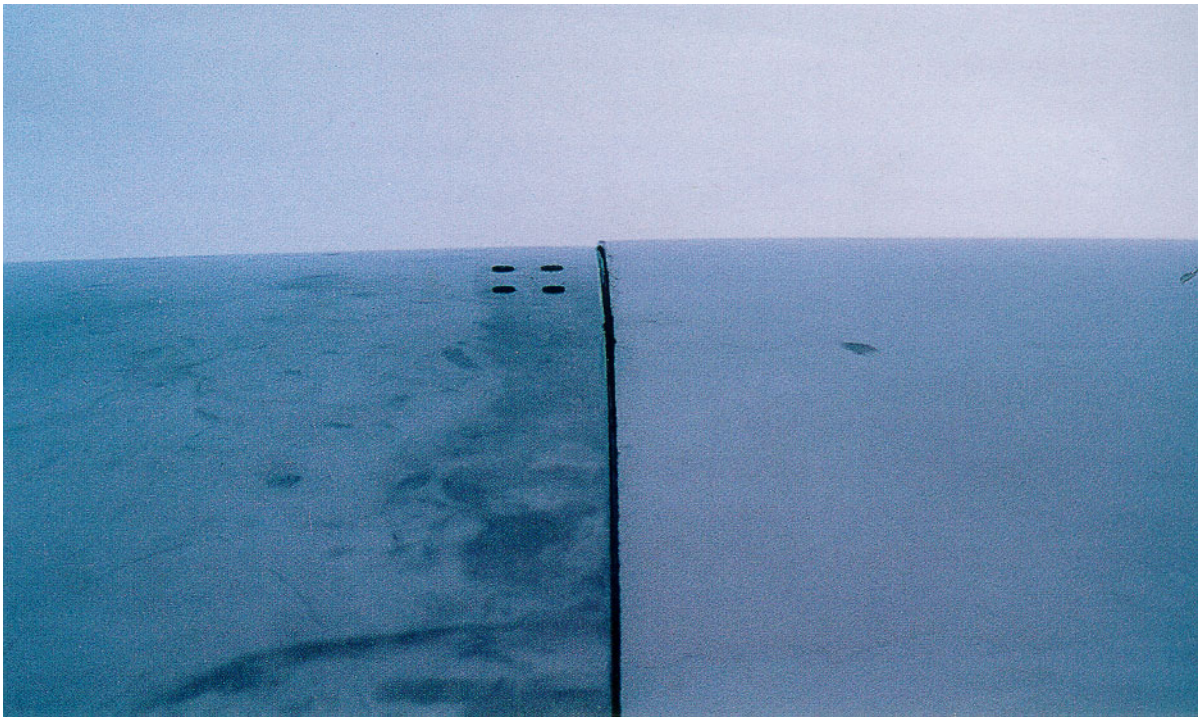


Engine step

leakage traces



Distance due to leakage



Step on engine cowl

3. A300/A310/A300-600 FAMILY

3. A300/A310/A300-600 FAMILY

The three aircraft of this widebody family have very similar airframes. Values given are best estimates for each aircraft.

As a simple fact, the higher the flight hours, the greater is the effect of aerodynamic deterioration on fuel consumption. For that reason, assumptions about flight hours per year are very important and can cause considerable differences, depending on each individual case. Based on data reported by all Airbus operators, the following flight hours (FH) per year per aircraft were assumed based on 1995 data.

	FH / Year	Nominal Consumption US GAL / Year
A300	2200	12450
A310	3200	14600
A300/600	2600	13700

Drag penalty values for each item are given in the tables on pages 28 to 69, representing an average for the whole widebody family and have determined considering a fictive airplane which in average Burns 13100 US Gallons / Year.

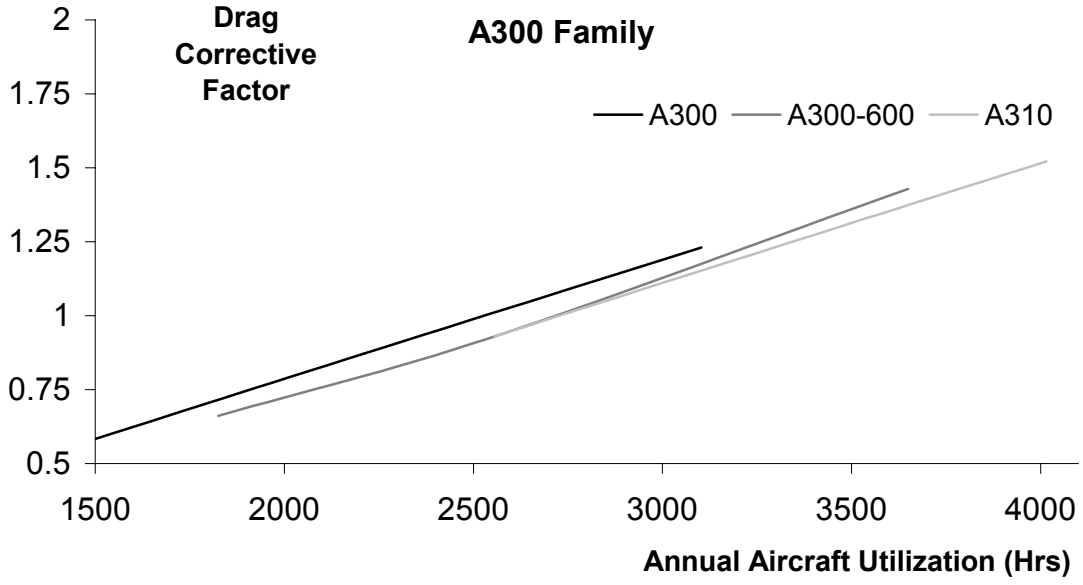
The manhours required for each item are given as a guideline.

The accuracy is high enough to allow a comparison between fuel burn penalties and the associated maintenance costs.

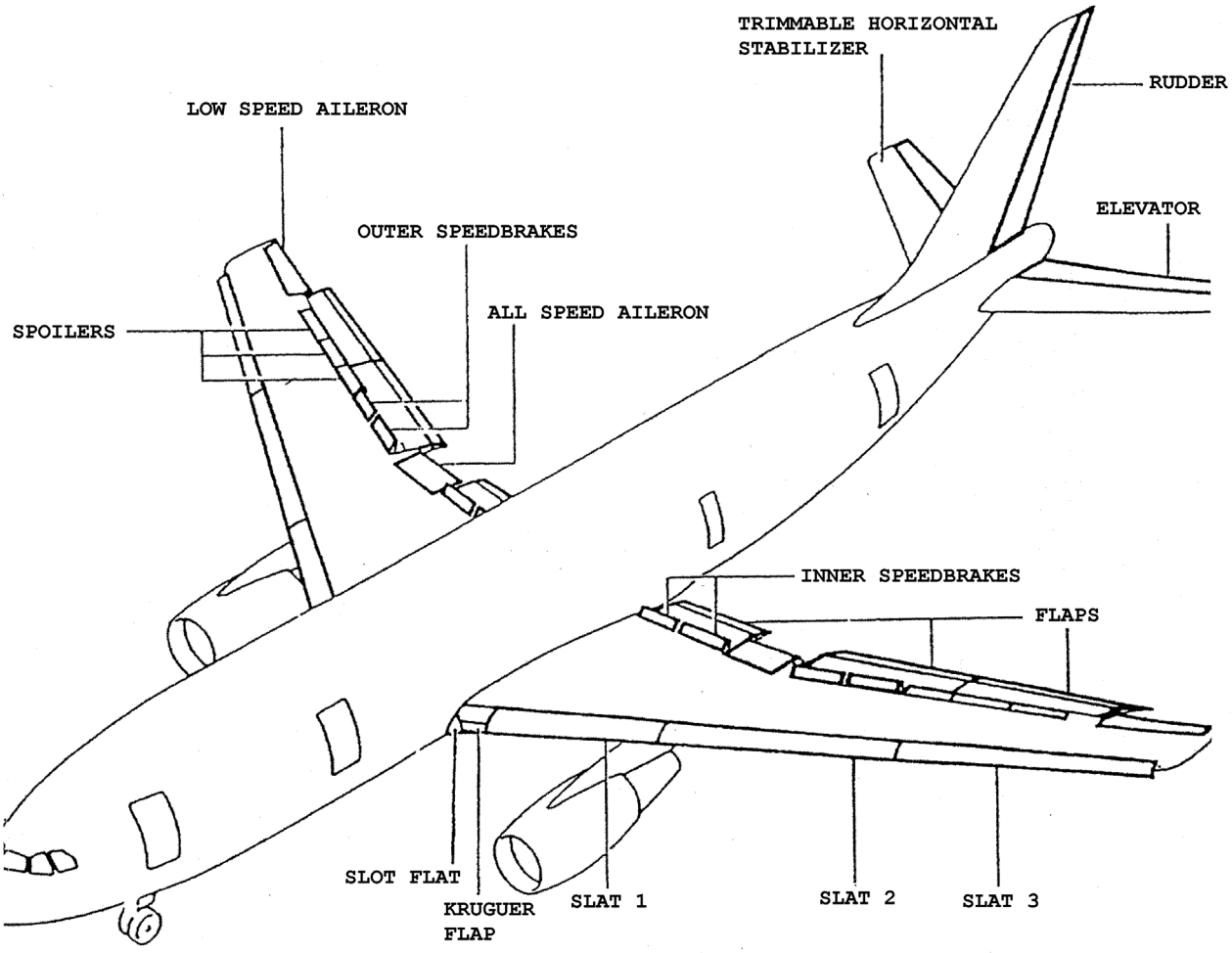
Corrective factor for drag penalty

If there is a need to determine aircraft fuel penalties with greater accuracy and/or if the airline has a different aircraft utilisation, corrective factors to apply to the yearly fuel penalty (in US gallons or US$) can be introduced in relation to the annual aircraft utilisation.

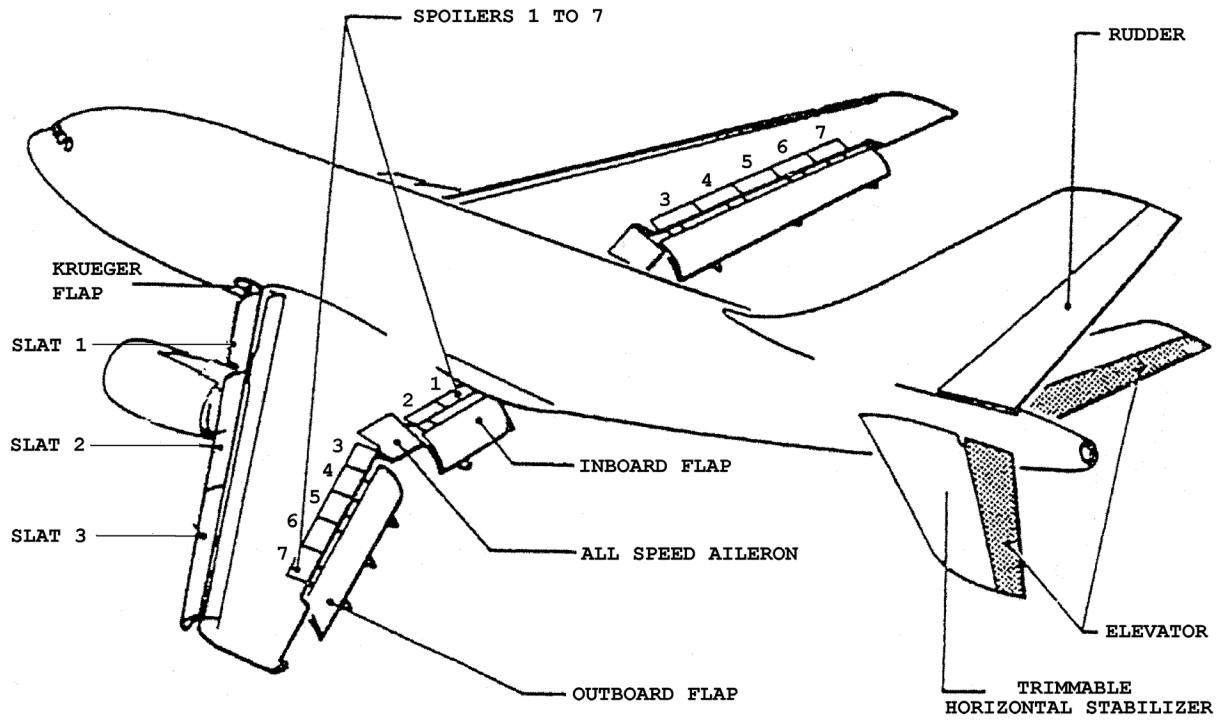
This corrective factor takes into account the geometrical differences compared to the fictive airplane used to determine the drag penalty values as well as the operational differences (nbr of flying hours per year and associated fuel consumption/hours)



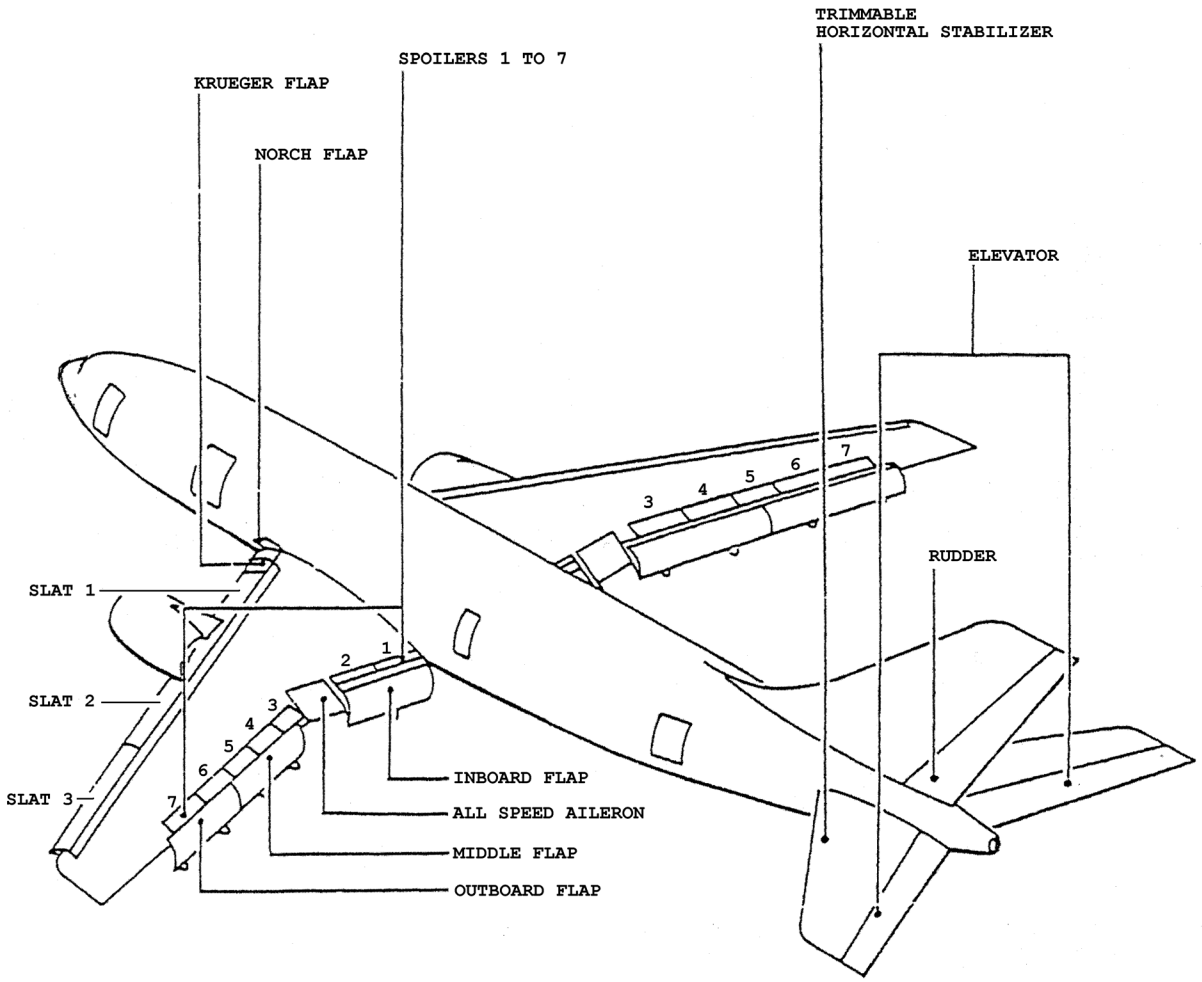
A300


TRIMMABLE HORIZONTAL STABILIZER
RUDDER
LOW SPEED AILERON
ELEVATOR
OUTER SPEEDBRAKES
SPOILERS
ALL SPEED AILERON
INNER SPEEDBRAKES
FLAPS
SLOT FLAT
KRUGUER FLAP
SLAT 1
SLAT 2
SLAT 3

A310

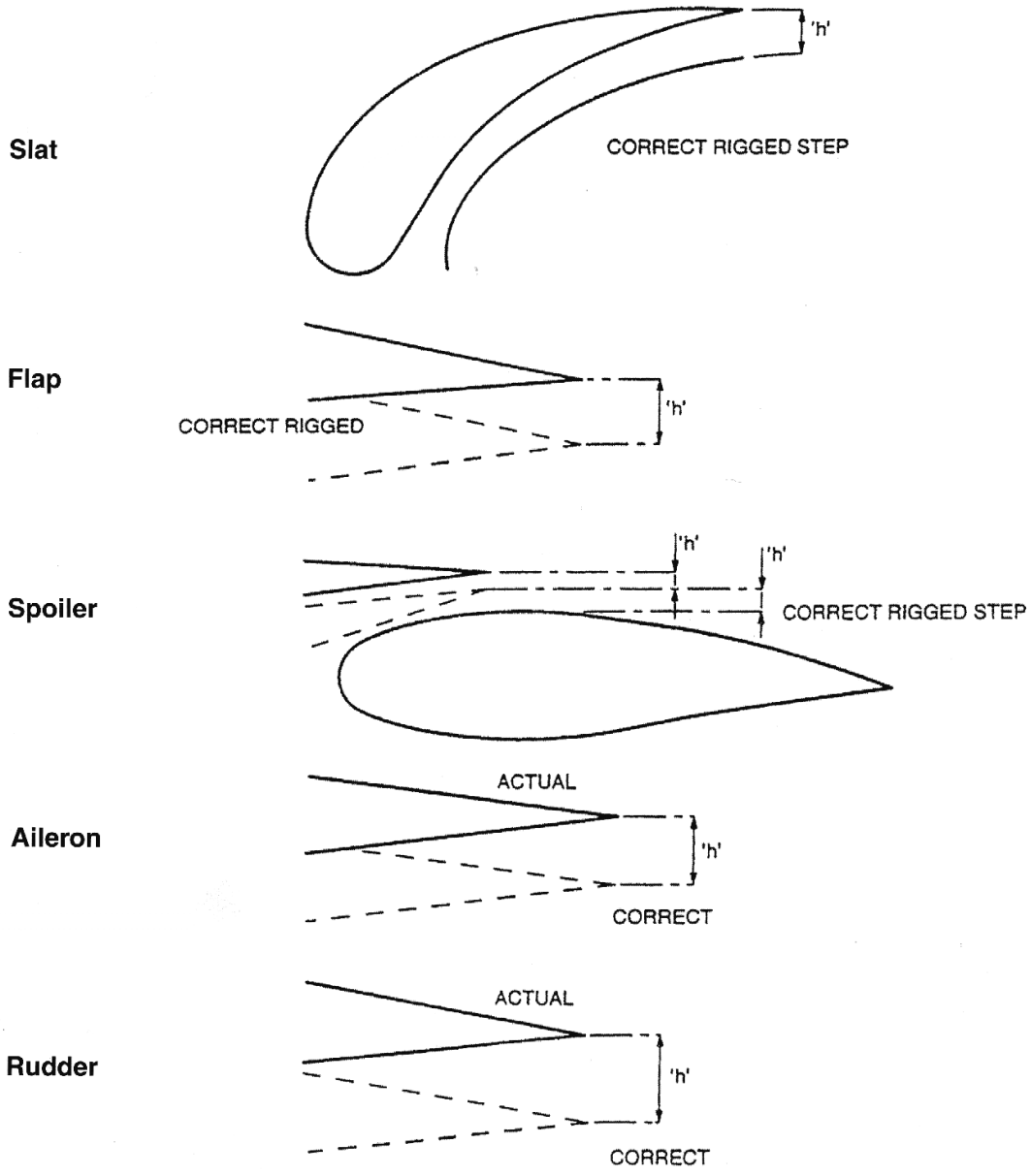

SPOILERS 1 TO 7
RUDDER
KRUEGER FLAP
SLAT 1
SLAT 2
SLAT 3
INBOARD FLAP
ALL SPEED AILERON
OUTBOARD FLAP
ELEVATOR
TRIMMABLE HORIZONTAL STABILIZER

A300-600


TRIMMABLE
HORIZONTAL STABILIZER
SPOILERS 1 TO 7
KRUEGER FLAP
NORCH FLAP
ELEVATOR
RUDDER
SLAT 1
SLAT 2
SLAT 3
INBOARD FLAP
ALL SPEED AILERON
MIDDLE FLAP
OUTBOARD FLAP

3.1 Misrigging of control surfaces

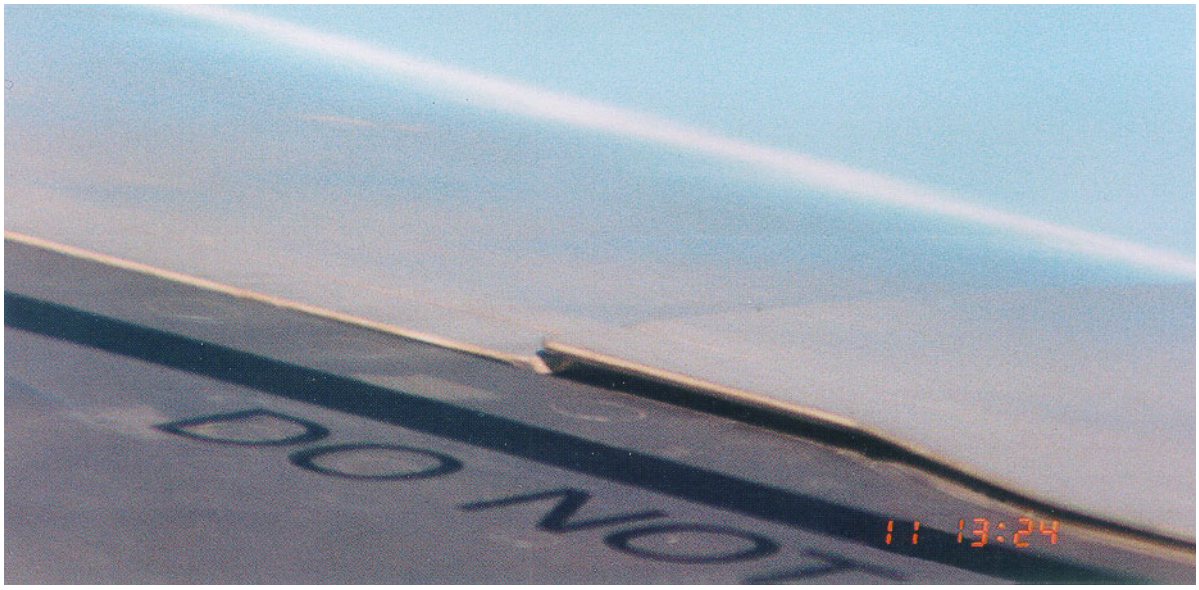
These items correspond to a specific control surface misrigging. The penalty is expressed by the difference in height at the control surface trailing edge between the misrigged and the correct position. The penalty corresponds to a one meter length of surface misrigging.

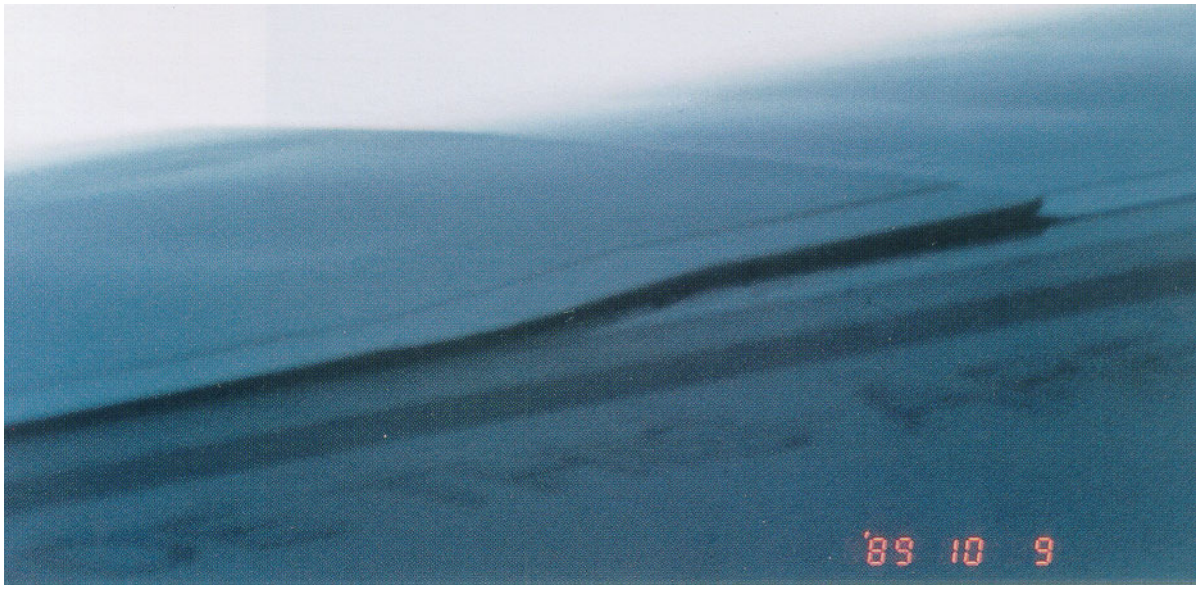


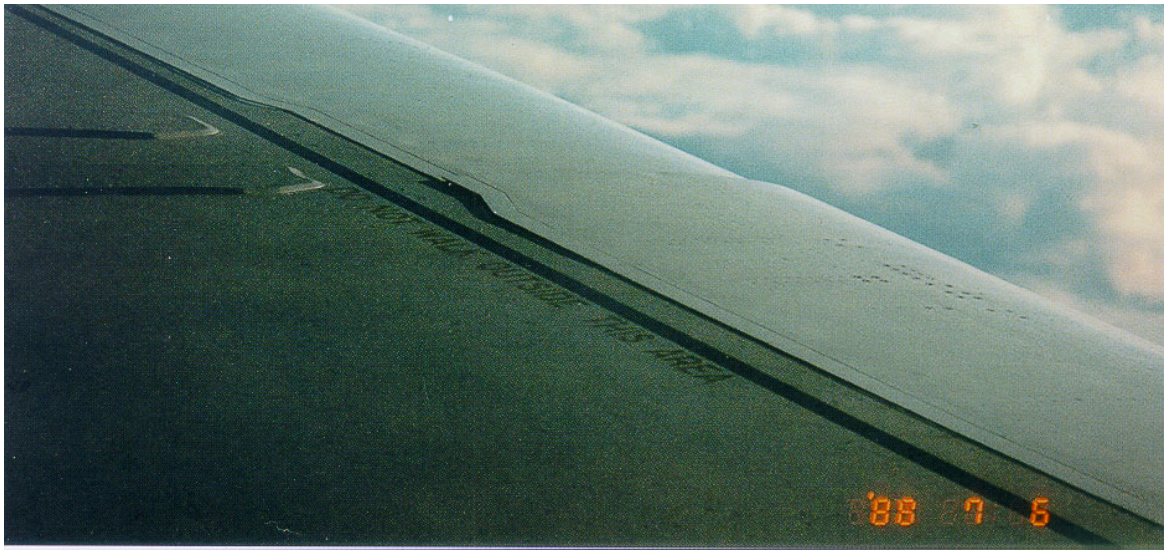
Control surface	Penalty in US gallons per year			**Penalty in US $ per year**			AMM reference	**Corrective action**		
	5mm height	10mm height	15mm height	5mm height	10mm height	**15mm height**		Men	Manhours	**Cost**
Slat 1 (per meter)	3,850	6,100	9,150	$ 2,310	$ 3,660	**$ 5,490**	27 80 00 27 81 00	2	5	**$ 250**
Slat 2 (per meter)	5,190	8,220	12,330	$ 3,110	$ 4,930	**$ 7,400**	27 80 00 27 81 00	2	5	**$ 250**
Slat 3 (per meter)	7,700	12,200	18,300	$ 4,620	$ 7,320	**$ 10,980**	27 80 00 27 81 00	2	5	**$ 250**
Flap	810	1,490	2,060	$ 490	$ 890	**$ 1,230**	27 51 00 27 54 00	2	6	**$ 300**
Spoiler	3,060	6,850	10,220	$ 1,840	$ 4,110	**$ 6,130**	27 61 00 27 62 00	1	2	**$ 100**
Aileron	810	1,500	2,120	$ 490	$ 900	**$ 1,270**	27 11 00	1	3	**$ 150**
Rudder	1,350	2,350	3,550	$ 810	$ 1,410	**$ 2,130**	27 21 00 27 24 00	2	4	**$ 200**
Misalign-ment at flap track fairing	680	1,360	1,700	$ 410	$ 820	**$ 1,020**	05 25 30	2	5	**$ 250**

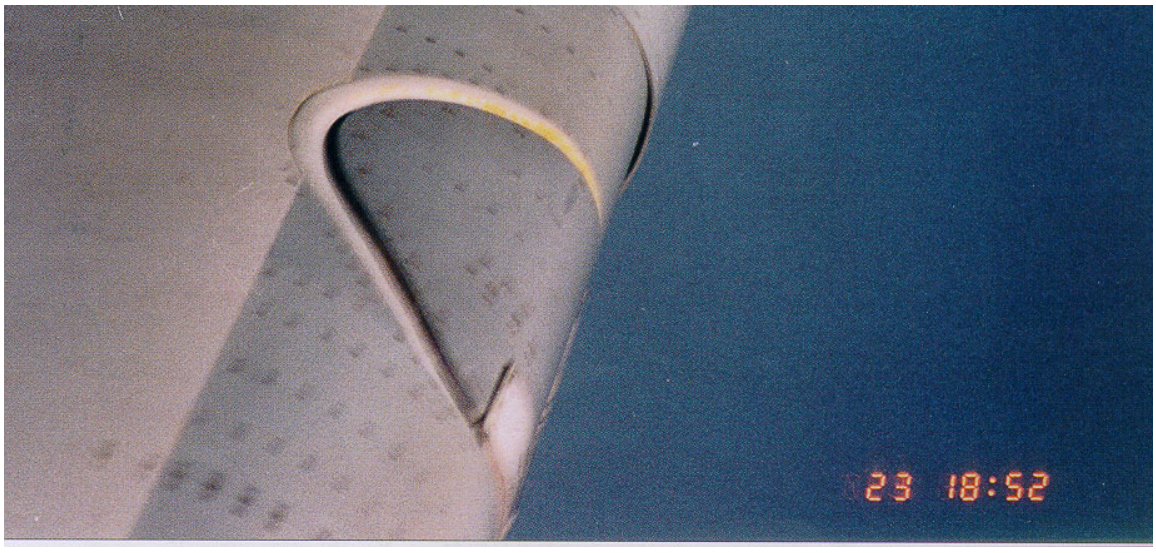
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Misrigged slats

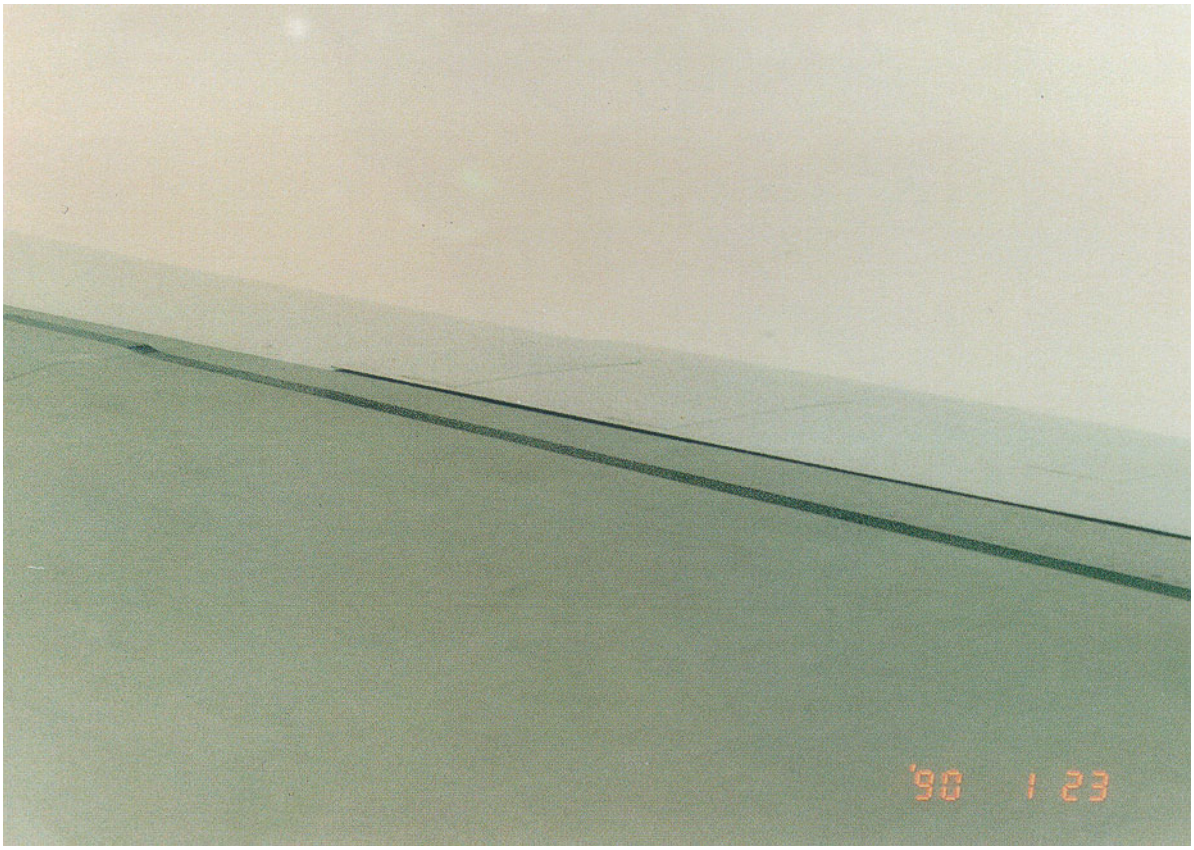




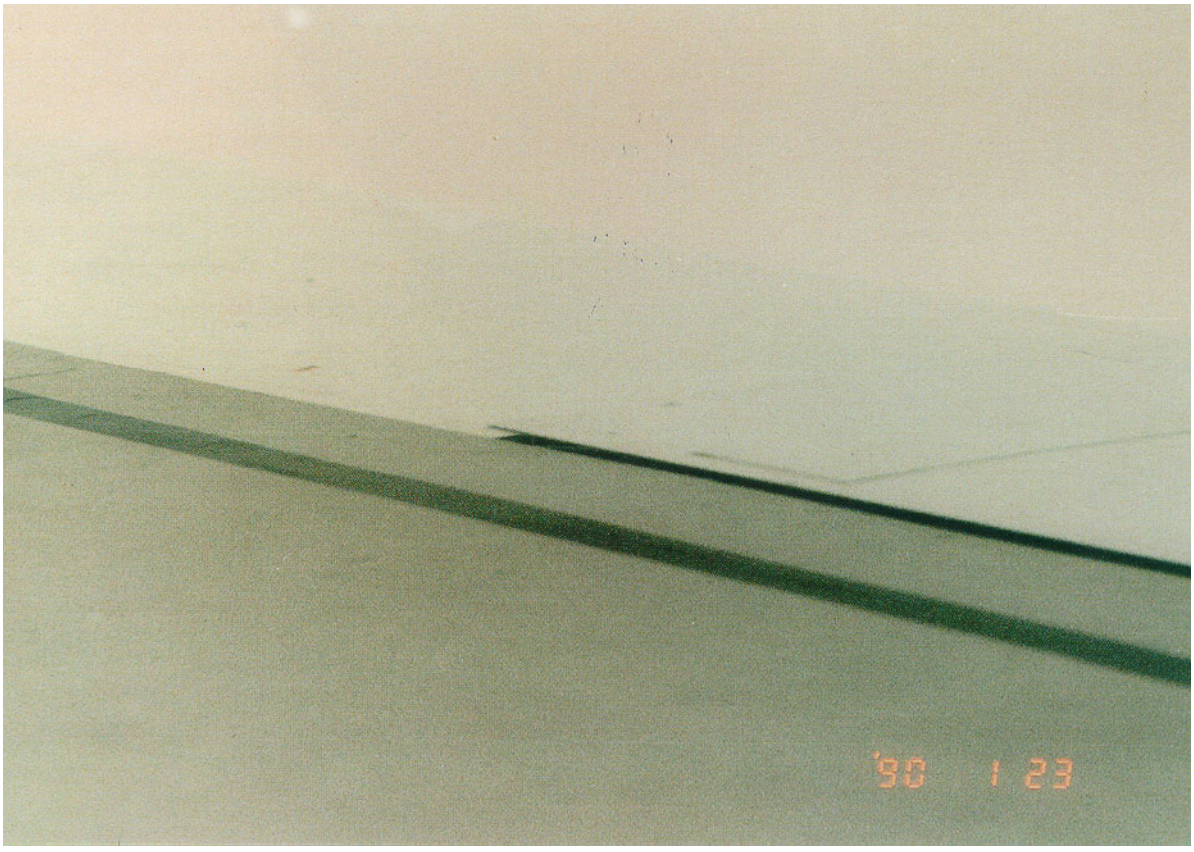


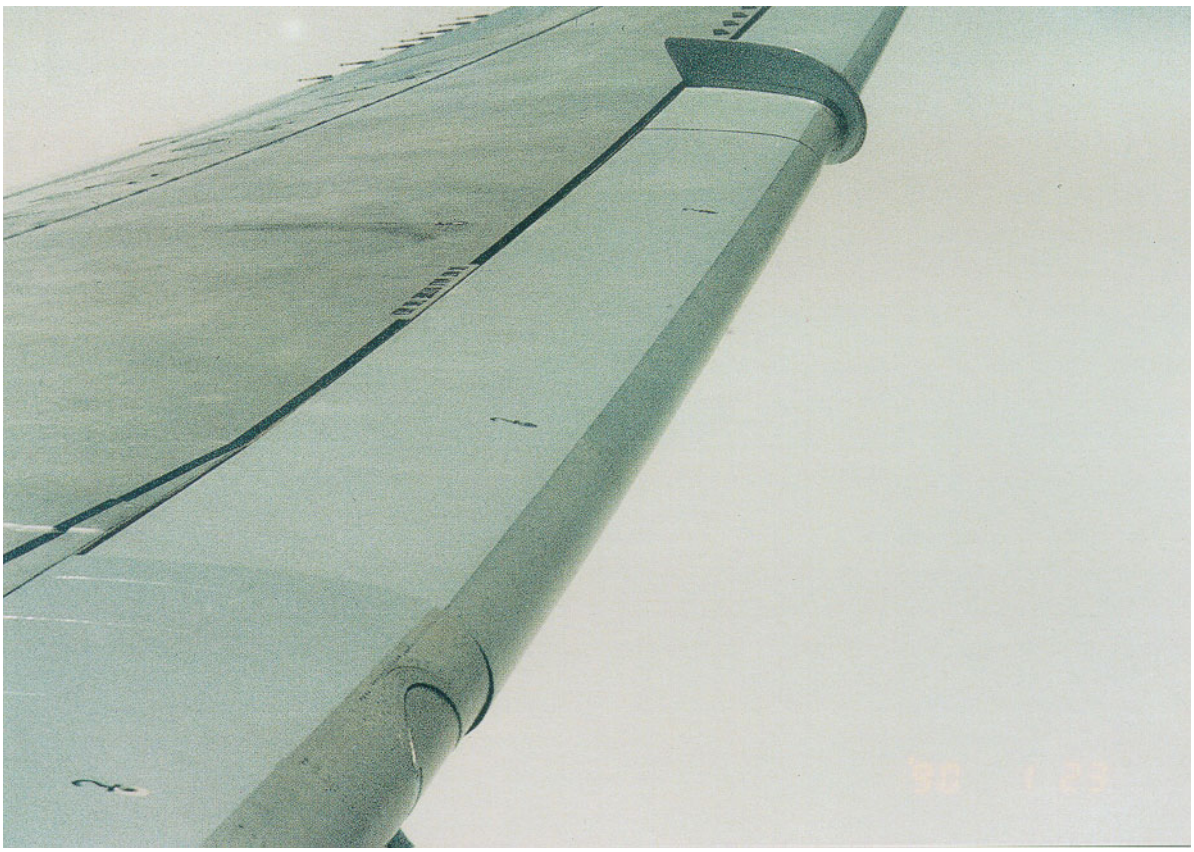


Misrigged slats

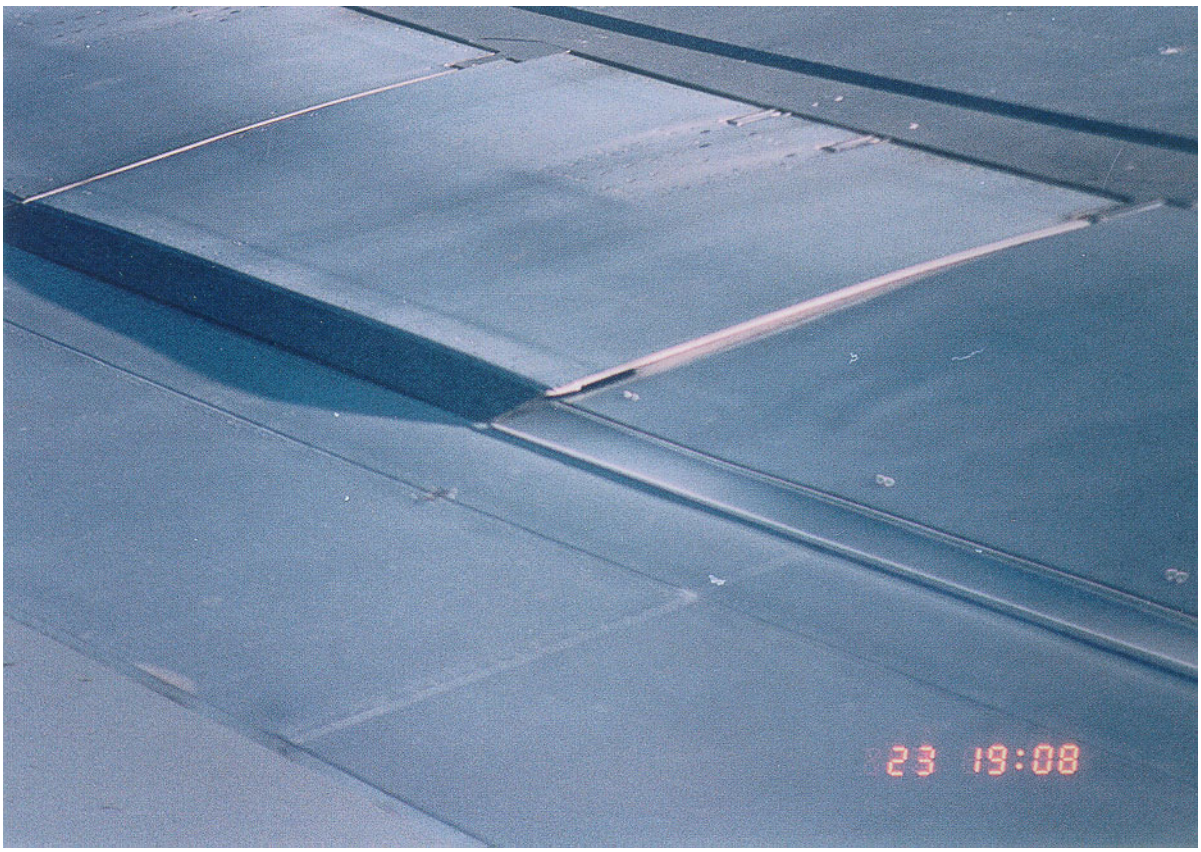


Misrigged slats

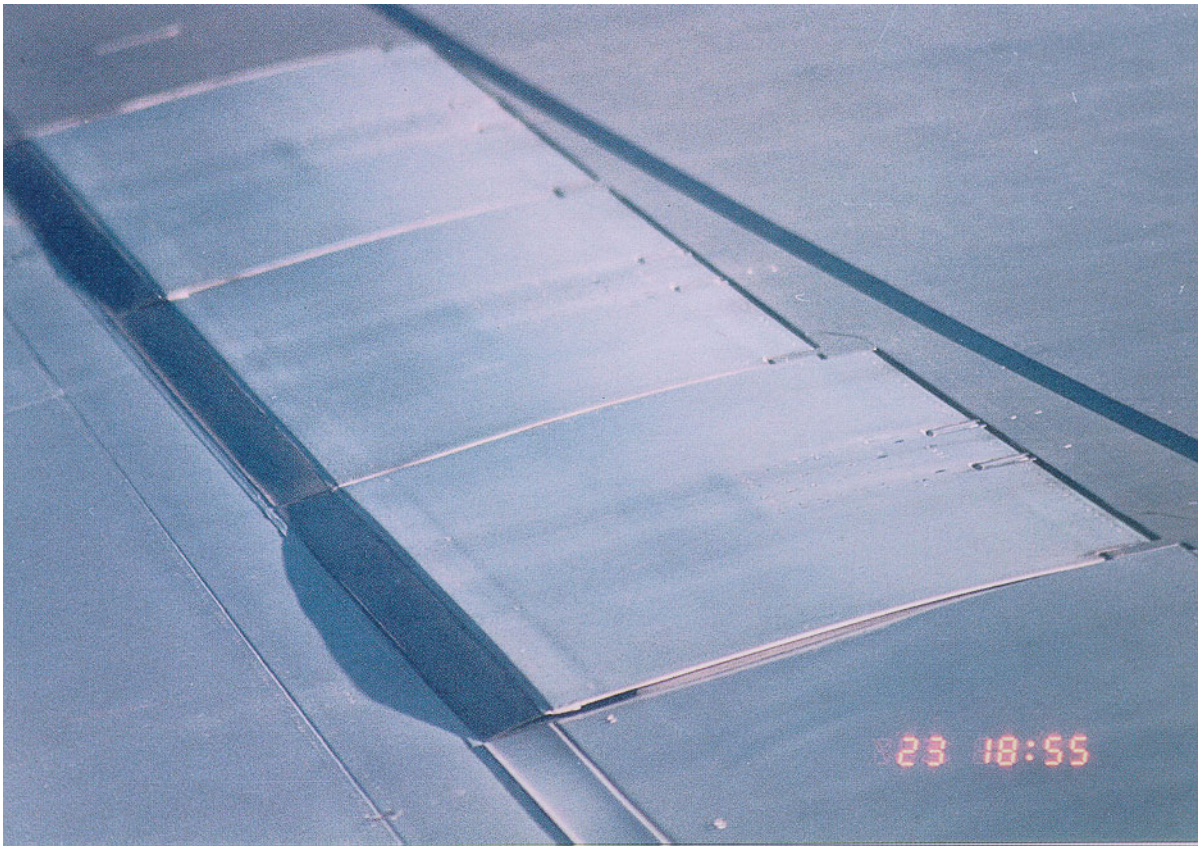




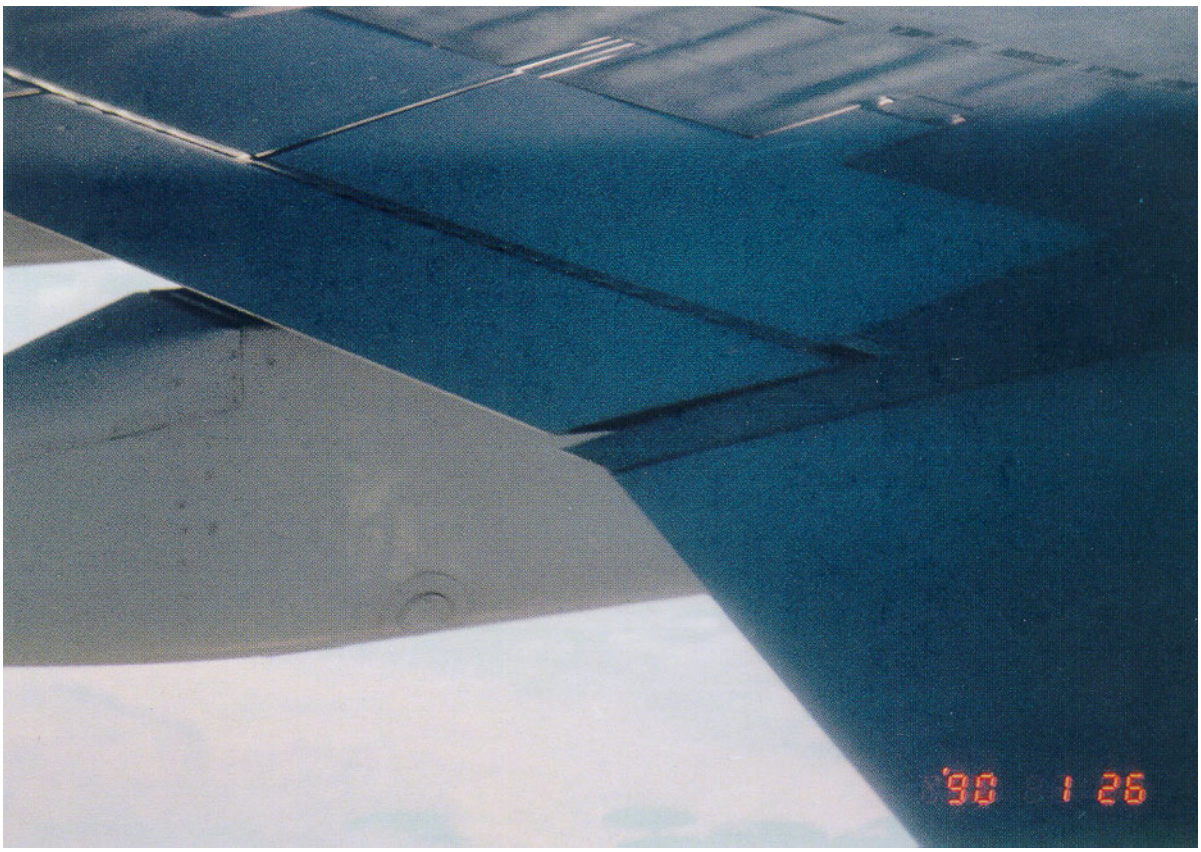
Misrigged slats



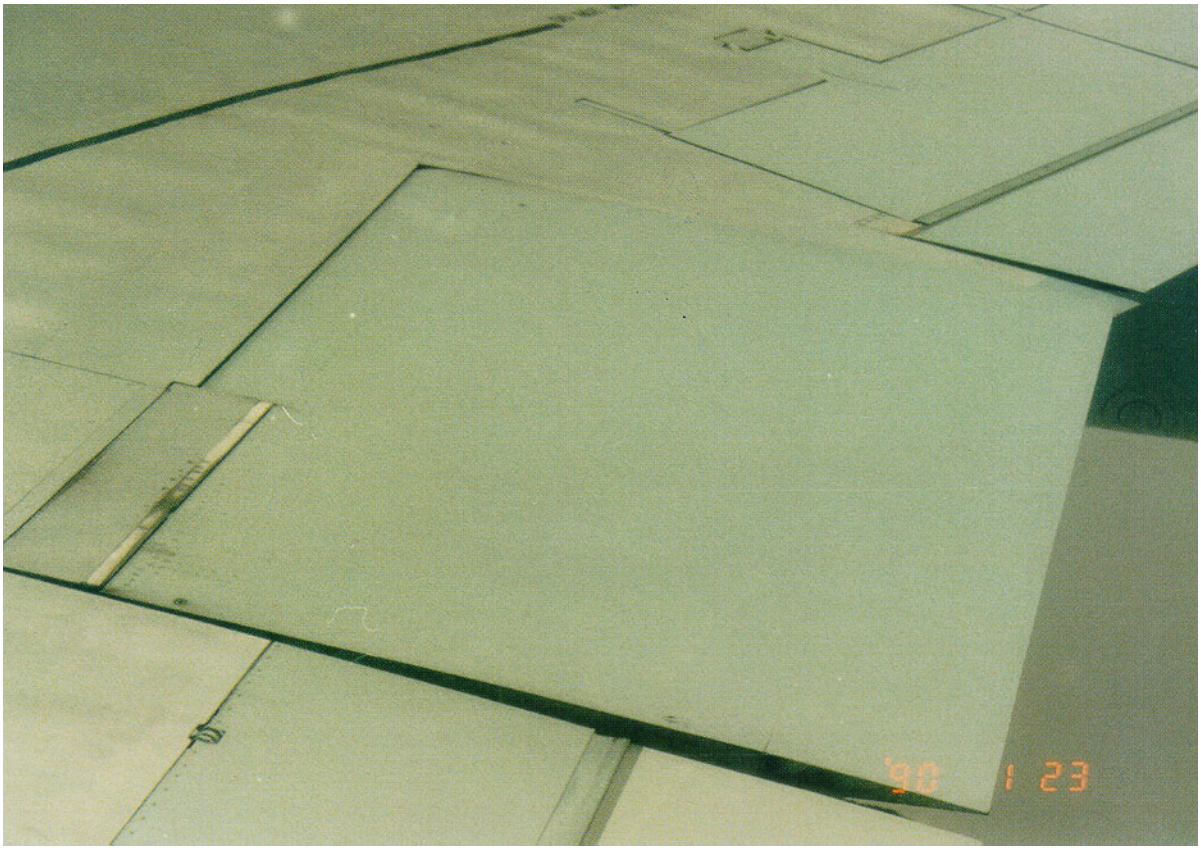
Misrigged spoiler



Misrigged spoiler



Misrigged flap



Misrigged aileron

3.2 Absence of seals on movable sections

Values are given per meter of missing seal.

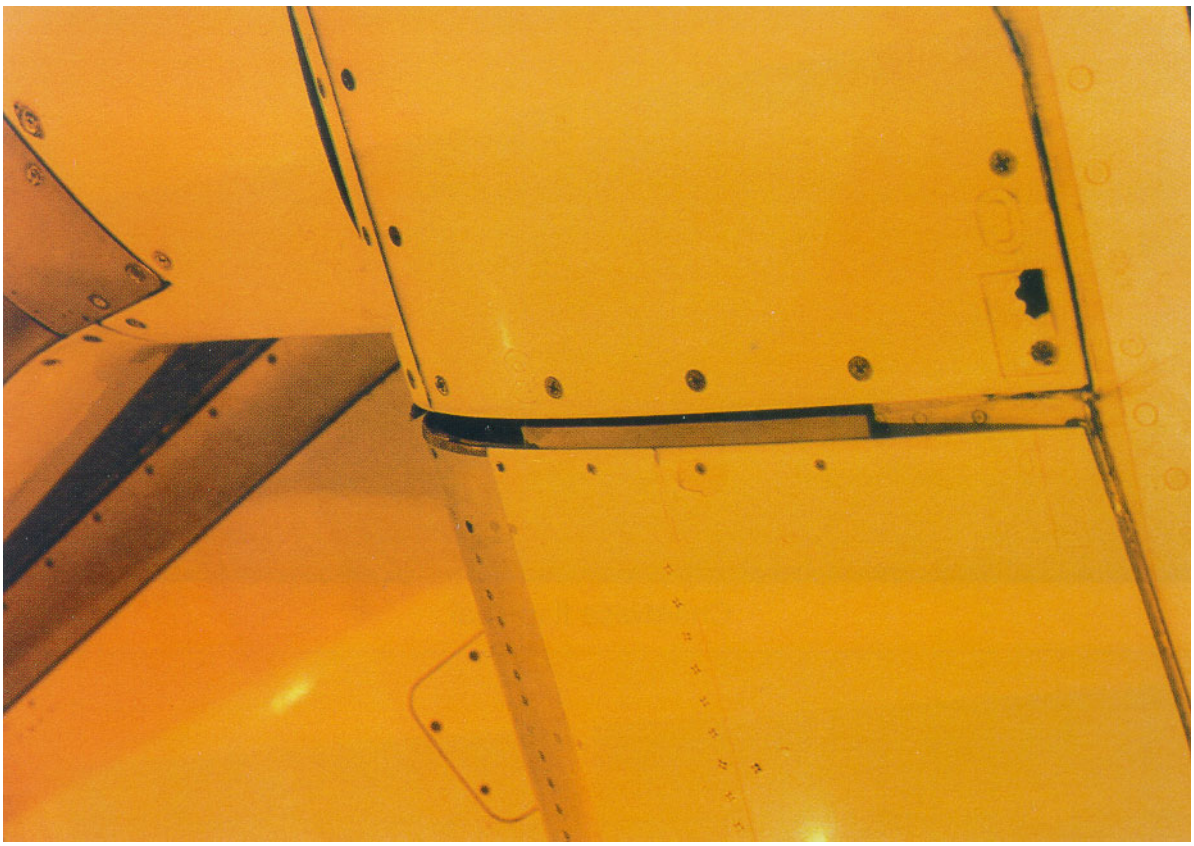
Control surface	Penalty in US gallons per year	**Penalty in US $ per year**	AMM reference	**Corrective action**		
Slat 1 (spanwise seal)	1,880	**$ 1,130**	57 42 00	1	2	**$ 100**
Slat 2 (spanwise seal)	2,800	**$ 1,680**	57 43 00	1	2	**$ 100**
Slat 3 (spanwise seal)	4,480	**$ 2,690**	57 44 00	1	2	**$ 100**
Flap (chordwise seal)	5,900	**$ 3,540**	27 50 00	1	2	**$ 100**
Wing surface-to-flap seal	2,150	**$ 1,290**	27 50 00	1	3	**$ 150**
Training edge missing from one spoiler	1,200	**$ 720**	27 61 63 27 61 54	1	2	**$ 100**
Aileron (chordwise seal)	5,900	**$ 3,540**	27 11 00	1	2	**$ 100**
Fairing and rubber seal missing from fin/fuselage junction	7,240	**$ 4,350**	53 53 00	1	3	**$ 150**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

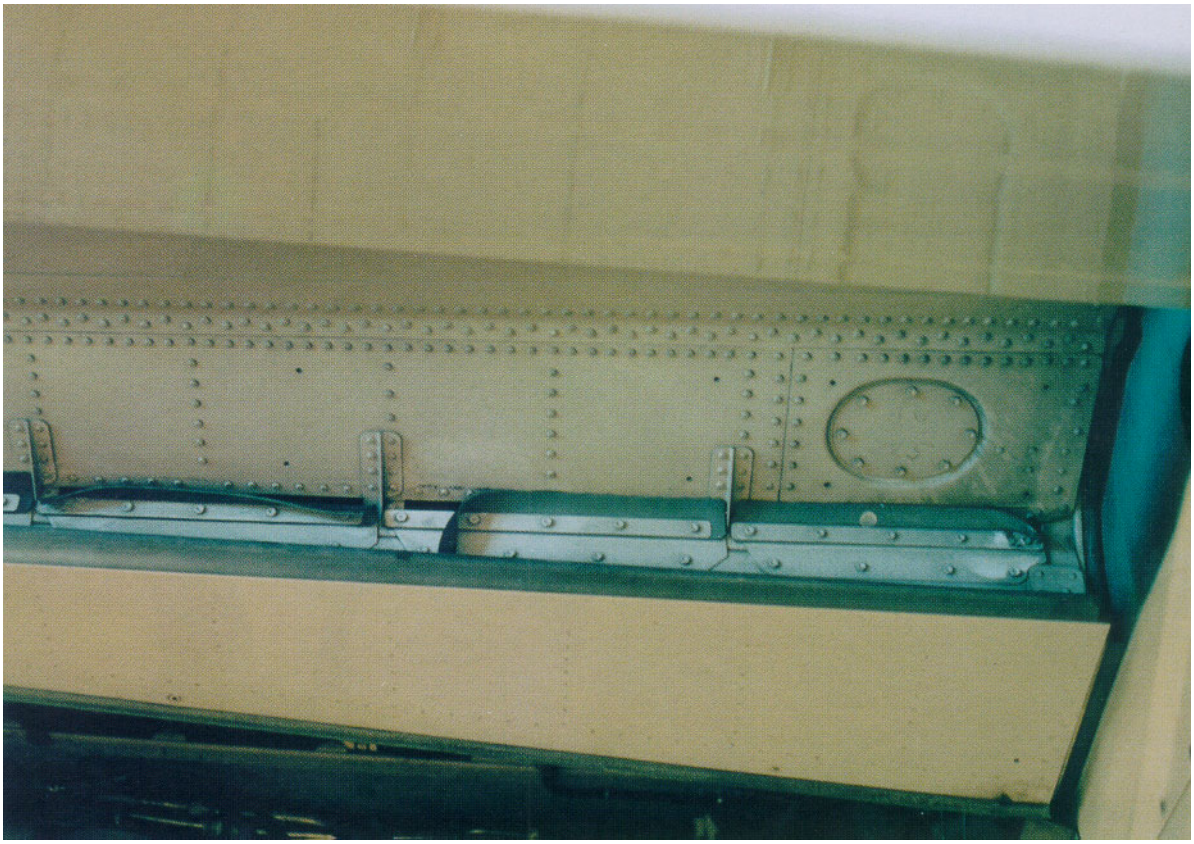
Absence of spanwise slat seal

No traces

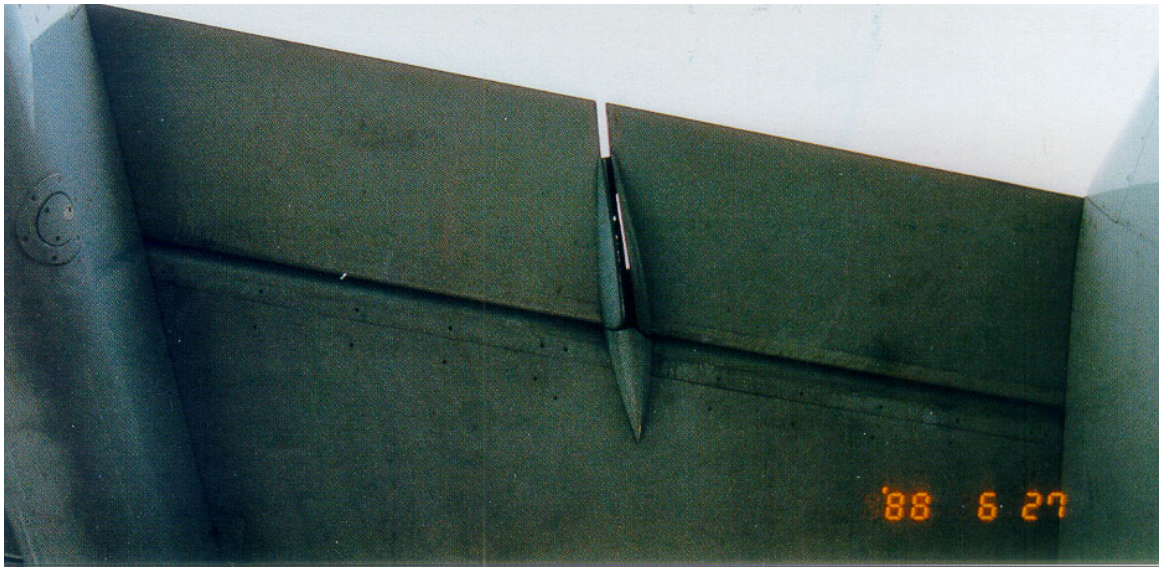
Slat seal



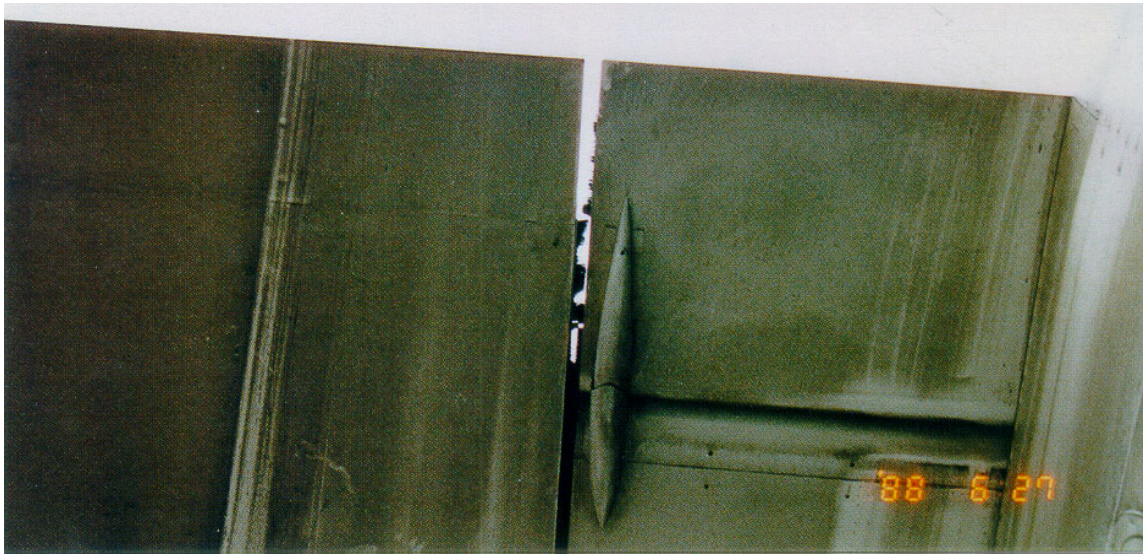
Chordwise slat seal



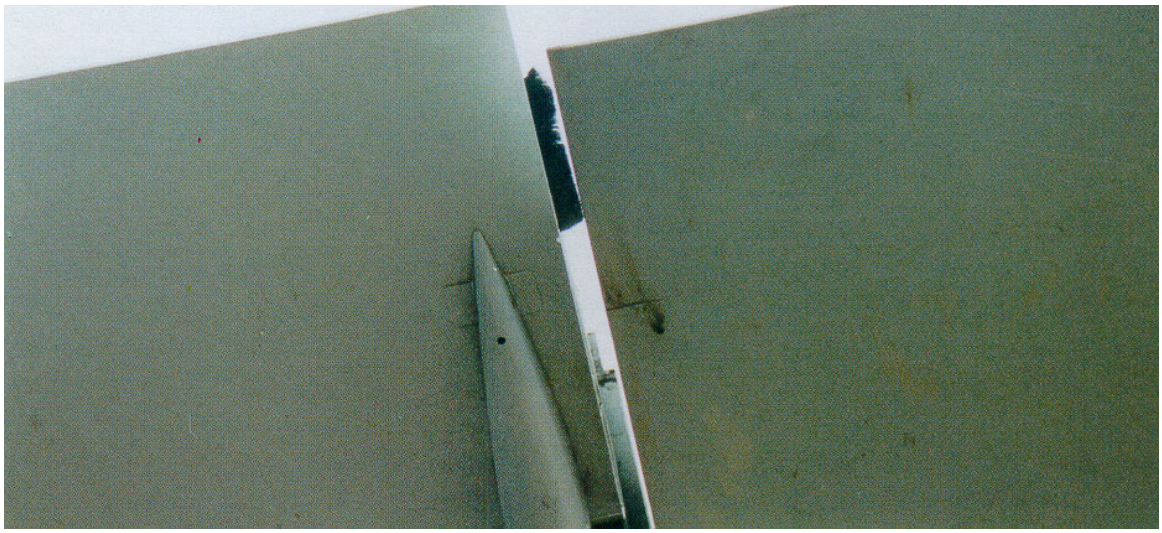
Wing under-surface-to-flap seal



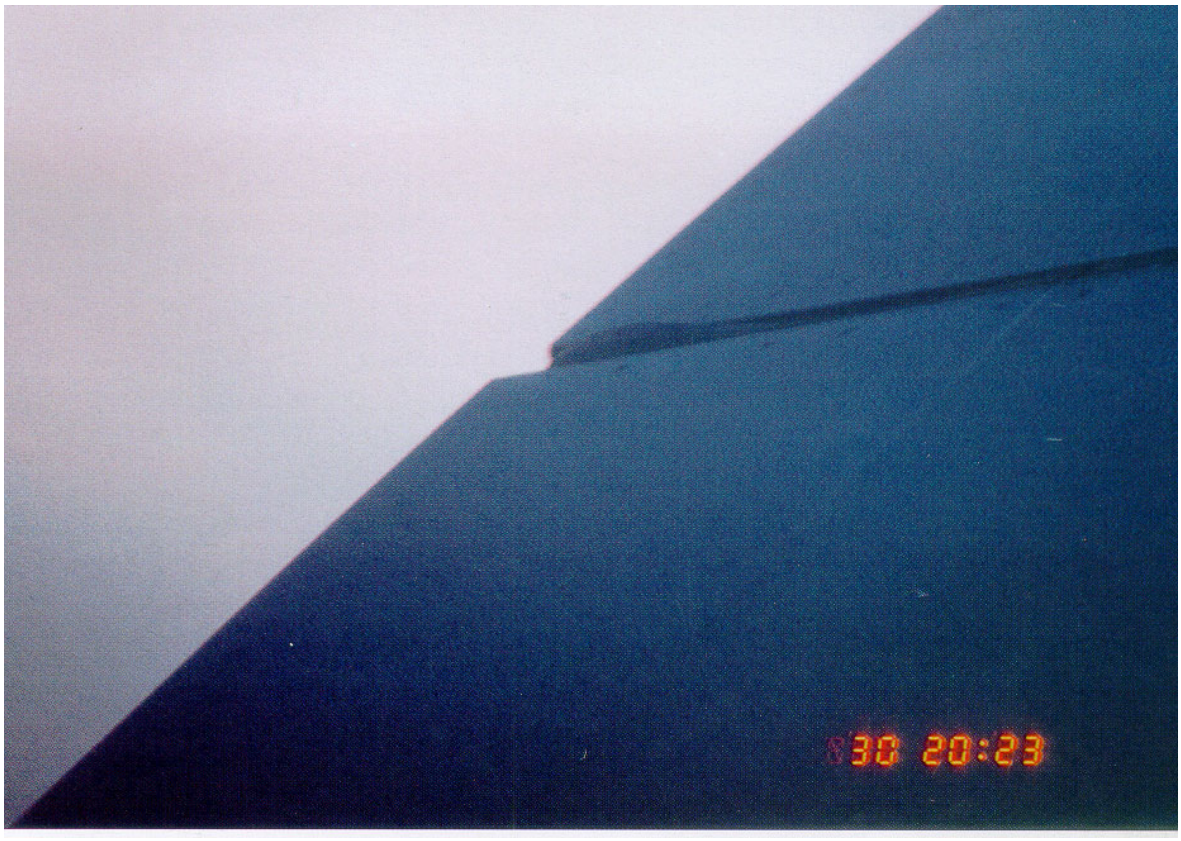
Chordwise flap seal



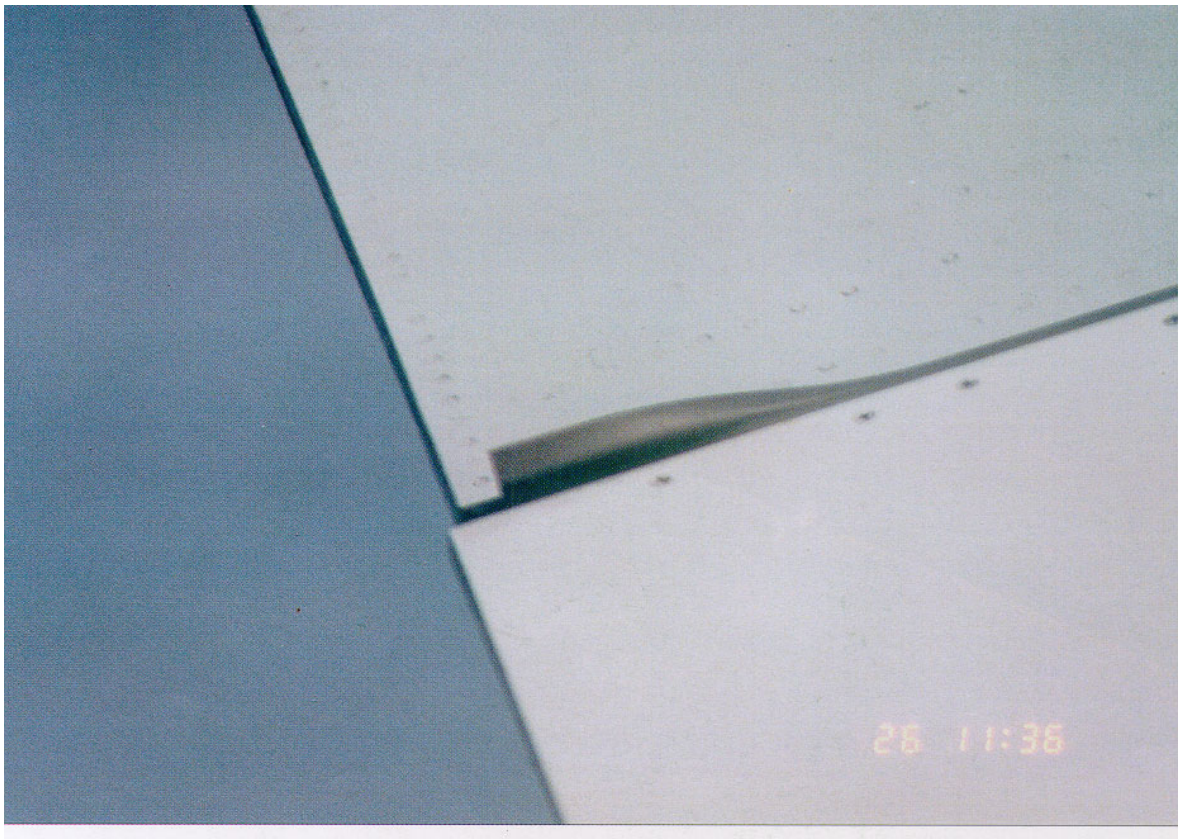
Aileron/flap seal

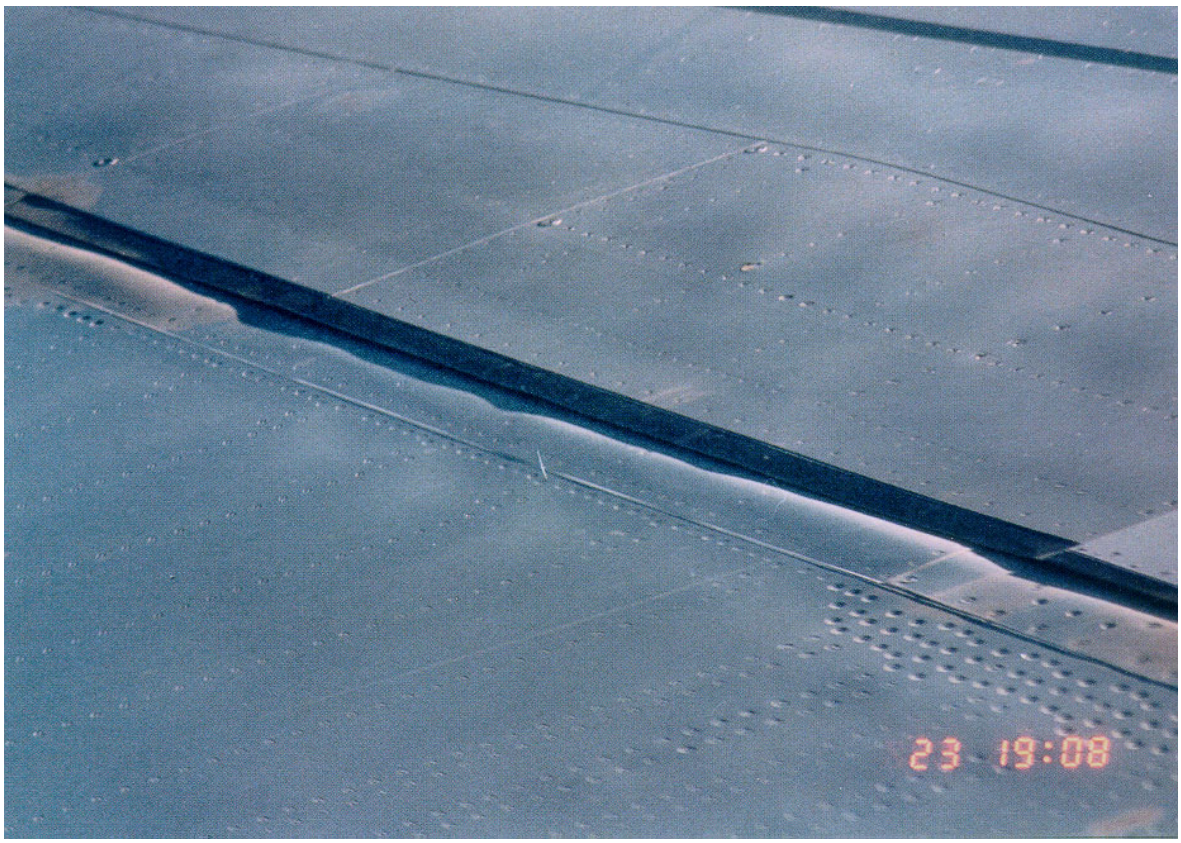


Aileron/flap seal

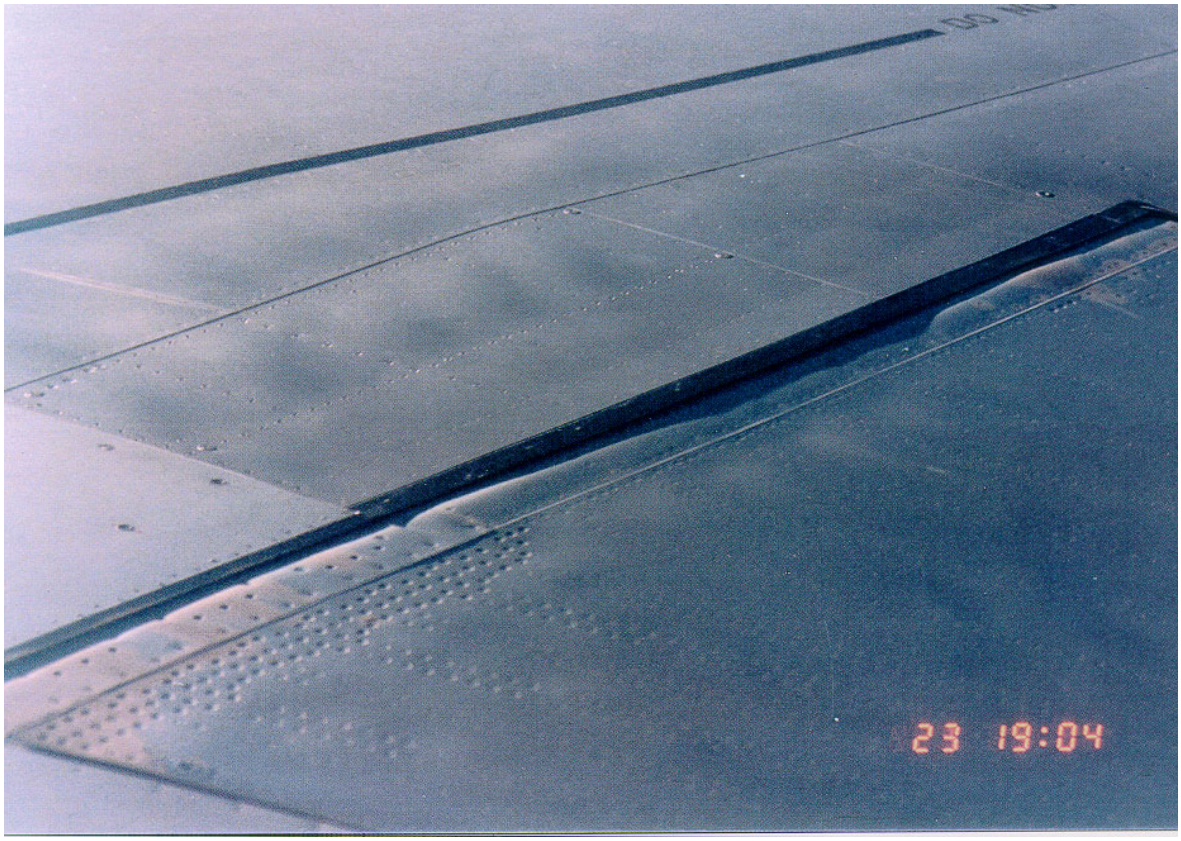


Chordwise aileron/flap seal





Spanwise aileron seal



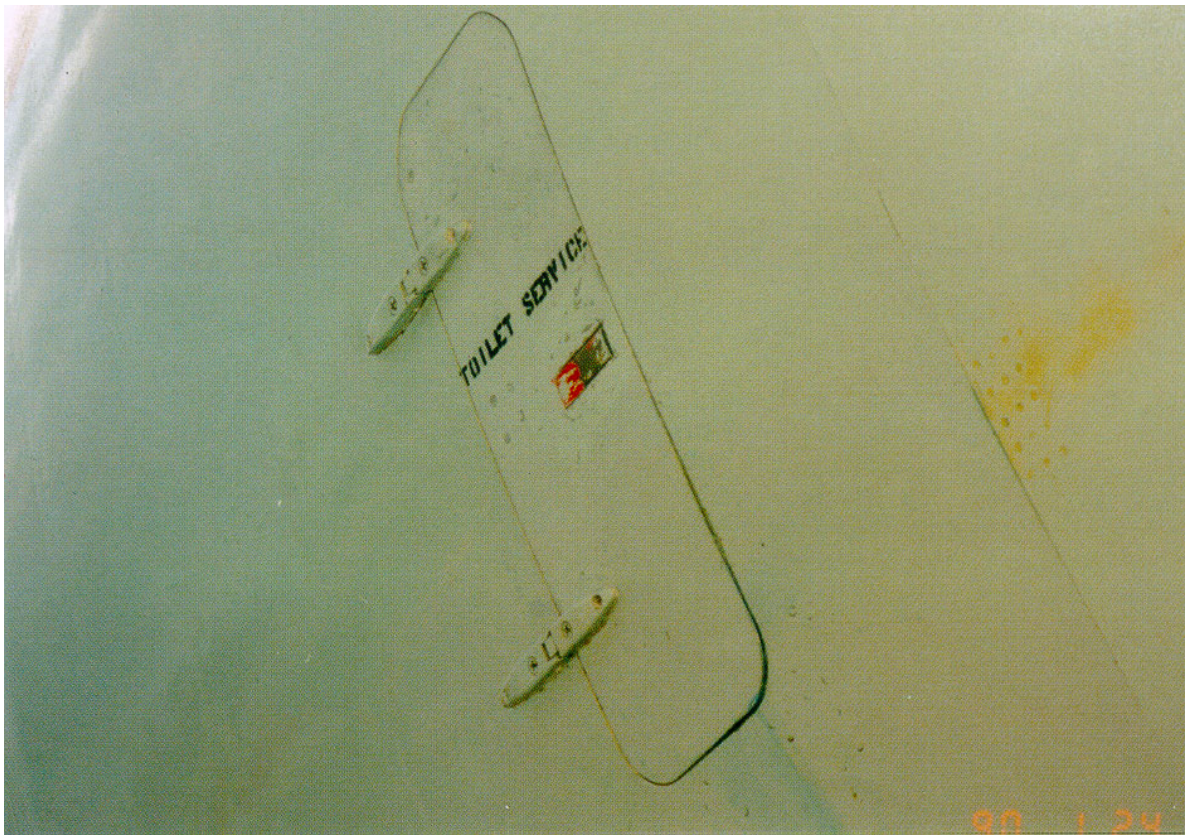
3.3 Missing parts

Values are given per meter of missing part.

Missing part	Penalty in US gallons per year	**Penalty in US $ per year**	AMM reference	**Corrective action**		
				Men	Manhours	**Cost**
Access door in the fuselage Zone 1 area	10,200	**$ 6,120**	52 41 00 52 42 00	1	3	**$ 150**
Access door in the fuselage Zone 2 area	7,650	**$ 4,590**	52 41 00 52 42 00	1	3	**$ 150**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Service door



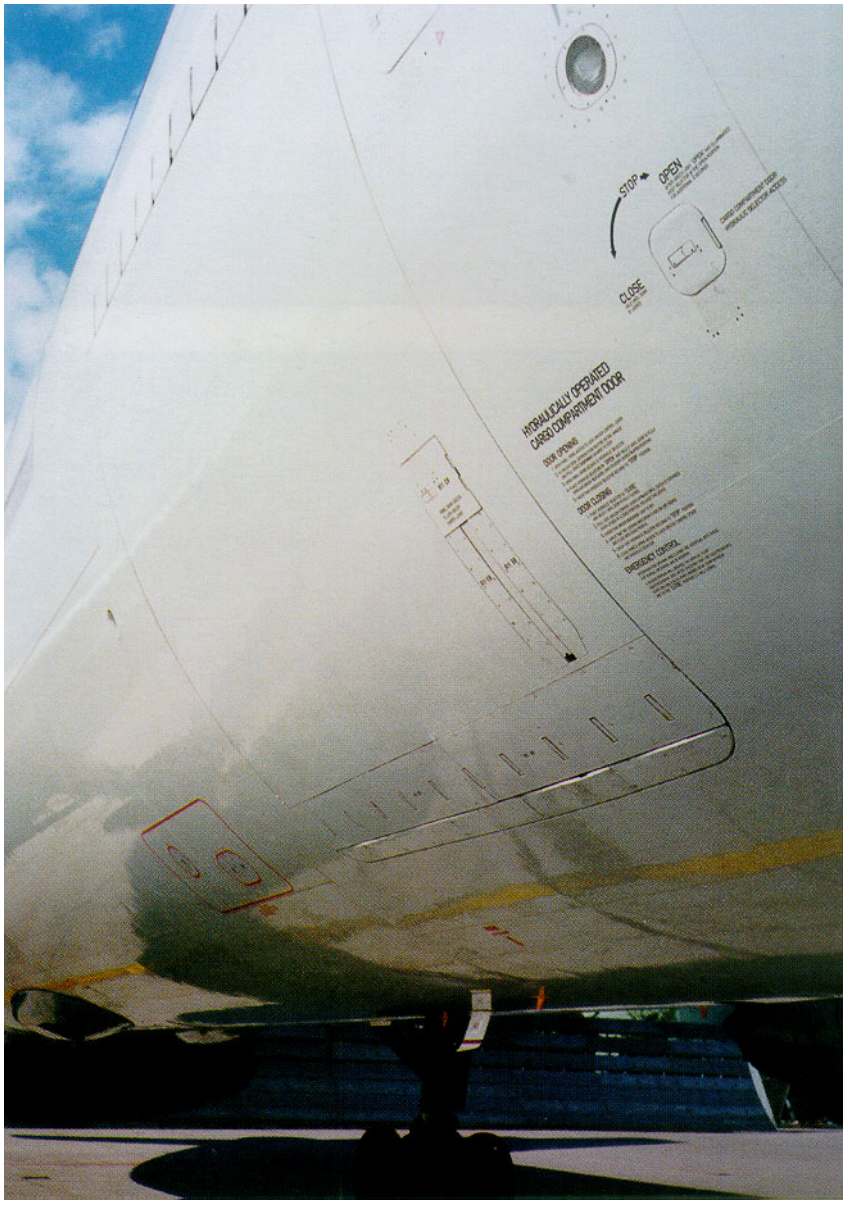
3.4 Mismatched surfaces

Values are given for a given step per meter of mismatch.

Mismatched surface	Penalty in US gallons per year		**Penalty in US $ per year**		AMM reference	**Corrective action**		
	5mm step	10mm step	5mm step	10mm step		Men	Manhours	**Cost**
Forward passenger door	1,710	3,940	$ 1,030	**$ 2,360**	52 10 11	2	8	**$ 400**
Mid passenger door (A300)	1,280	2,920	$ 770	**$ 1,750**	52 10 11	2	8	**$ 400**
Aft passenger door (A300)	480	1,100	$ 286	**$ 660**	52 10 11	2	8	**$ 400**
Aft passenger door (A310)	1,420	3,260	$ 850	**$ 1,960**	52 10 11	2	8	**$ 400**
Emergency exit (A300)	620	1,450	$ 370	**$ 870**	52 22 11	2	7	**$ 350**
Emergency exit (A310)	1,570	3,620	$ 940	**$ 2,170**	52 22 11	2	7	**$ 350**
Forward cargo door	1,870	4,270	$ 1,120	**$ 2,560**	52 31 11	2	13	**$ 650**
Aft cargo door	1,230	2,850	$ 740	**$ 1,710**	52 31 11	2	13	**$ 650**
Bulk door	700	1,780	$ 420	**$ 1070**	52 54 00	1	4	**$ 200**
Main landing gear door	1,080	2,710	$ 650	**$ 1,630**	32 12 11	2	8	**$ 400**
Nose landing gear door	1,540	3,520	$ 920	**$ 2,110**	32 22 11	2	6	**$ 300**
Access door in Zone 1 area	610	1,650	$ 370	**$ 990**	no procedure			
Radome misfit (maximum allowed)	670		**$ 400**		53 51 00	2	6	**$ 300**

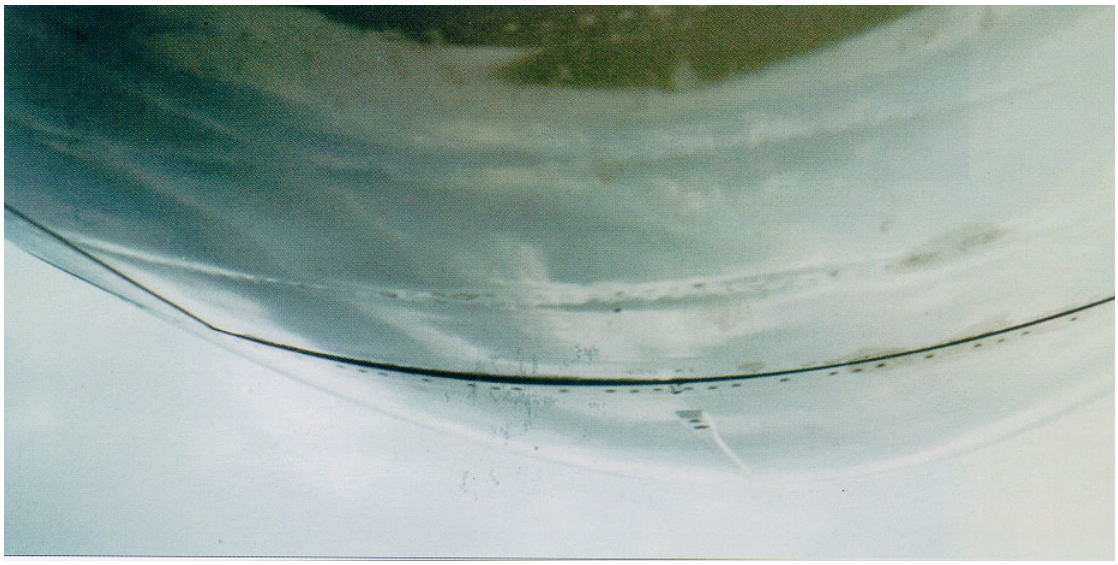
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Mismatched passenger doors

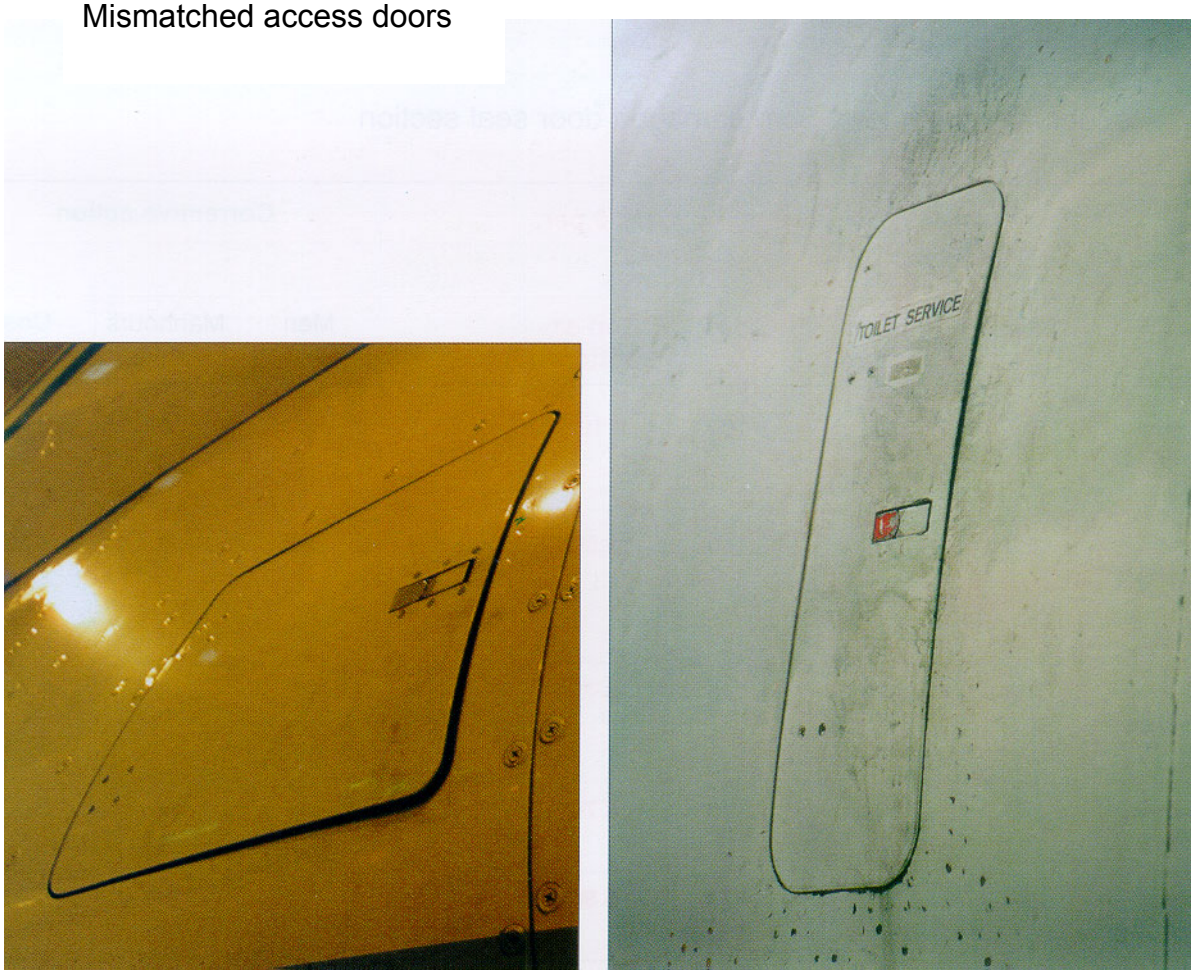

STOP
OPEN
CLOSE
HYDRAULICALLY OPERATED
CARGO COMPARTMENT DOOR

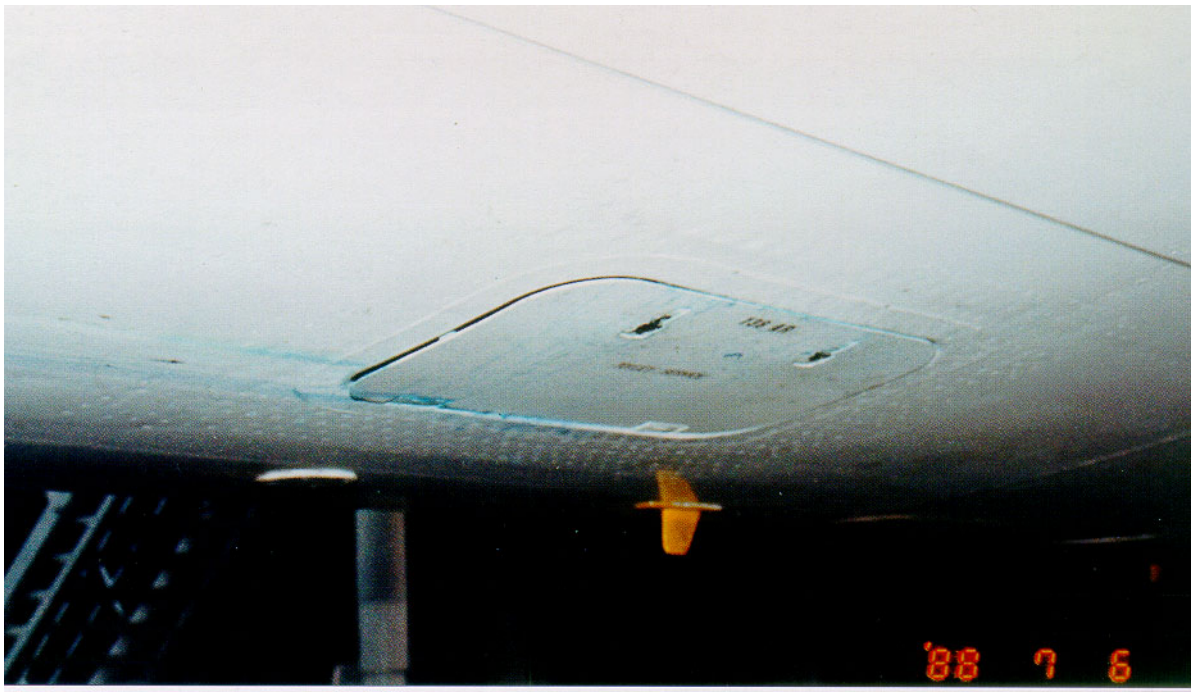
Cargo door

Radome misfit



Mismatched access doors



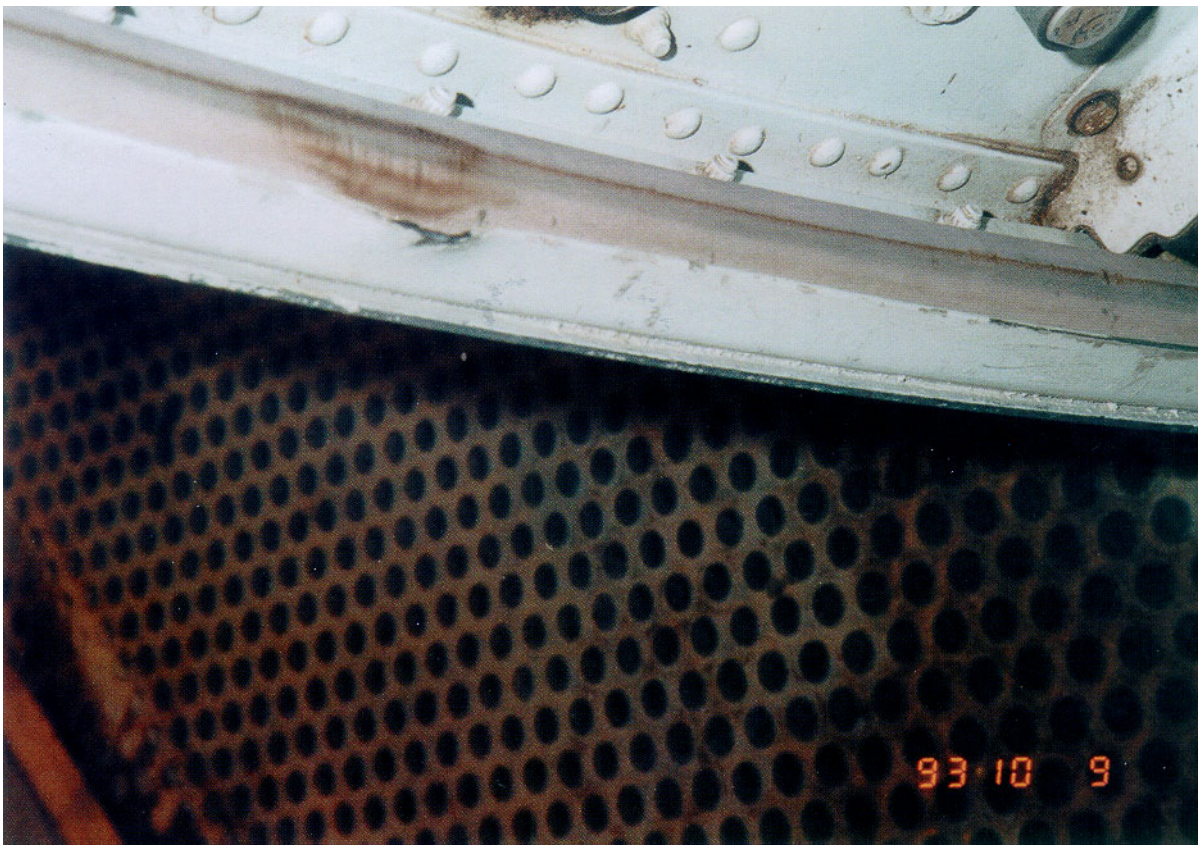


3.5 Door seal leakage

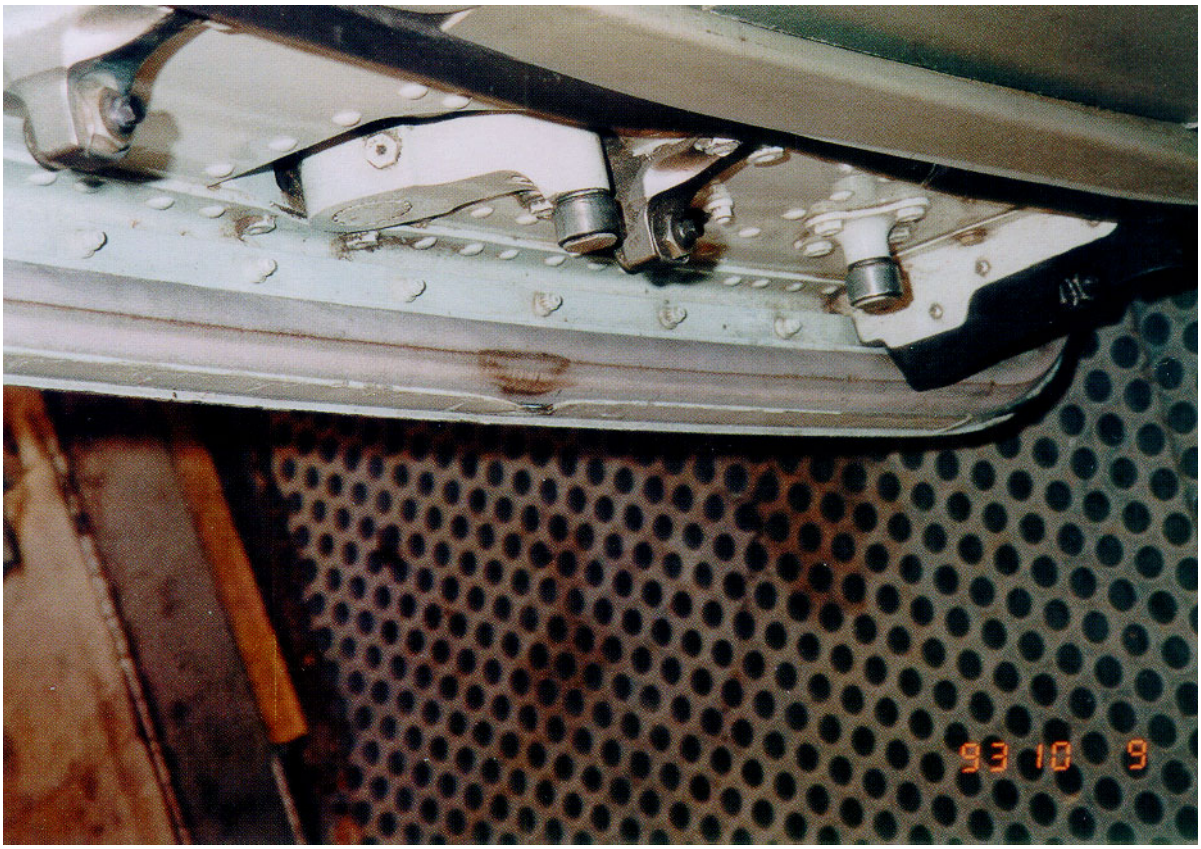
Values are given for a 5cm damaged door seal section.

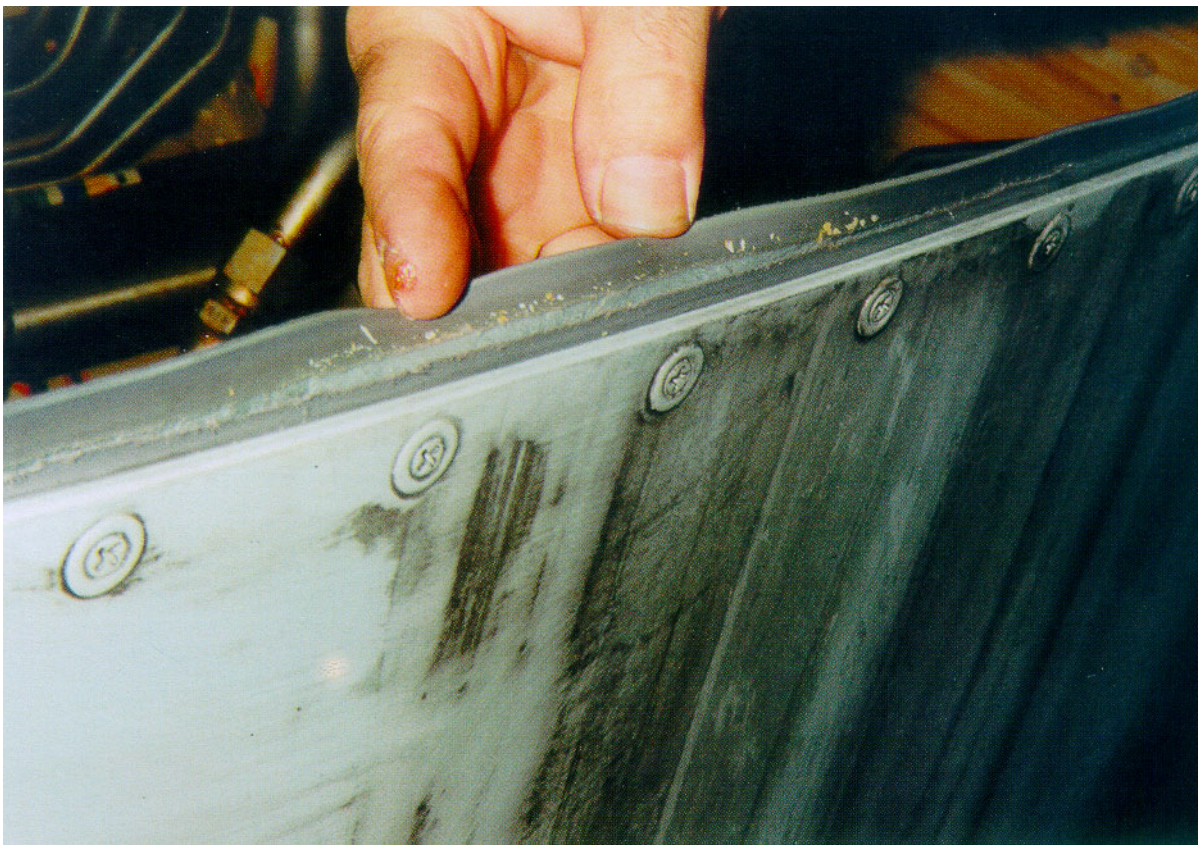
Item	Penalty in US gallons per year		Penalty in US $ per year		AMM reference	Corrective action		
	Sides	Top or bottom	Sides	Top or bottom		Men	Manhours	Cost
Forward passenger door	317	170	$ 190	**$ 100**	52 10 00	2	8	**$ 400**
Mid passenger door (A300)	260	150	$ 160	**$ 90**	52 10 00	2	8	**$ 400**
Aft passenger door	230	120	$ 140	**$ 70**	52 10 00	2	8	**$ 400**
Emergency exit	240	120	$ 140	**$ 70**	52 20 00	2	7	**$ 350**
Forward cargo door	290	150	$ 170	**$ 90**	52 30 00	2	12	**$ 600**
Aft cargo door	220	110	$ 130	**$ 70**	52 30 00	2	12	**$ 600**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

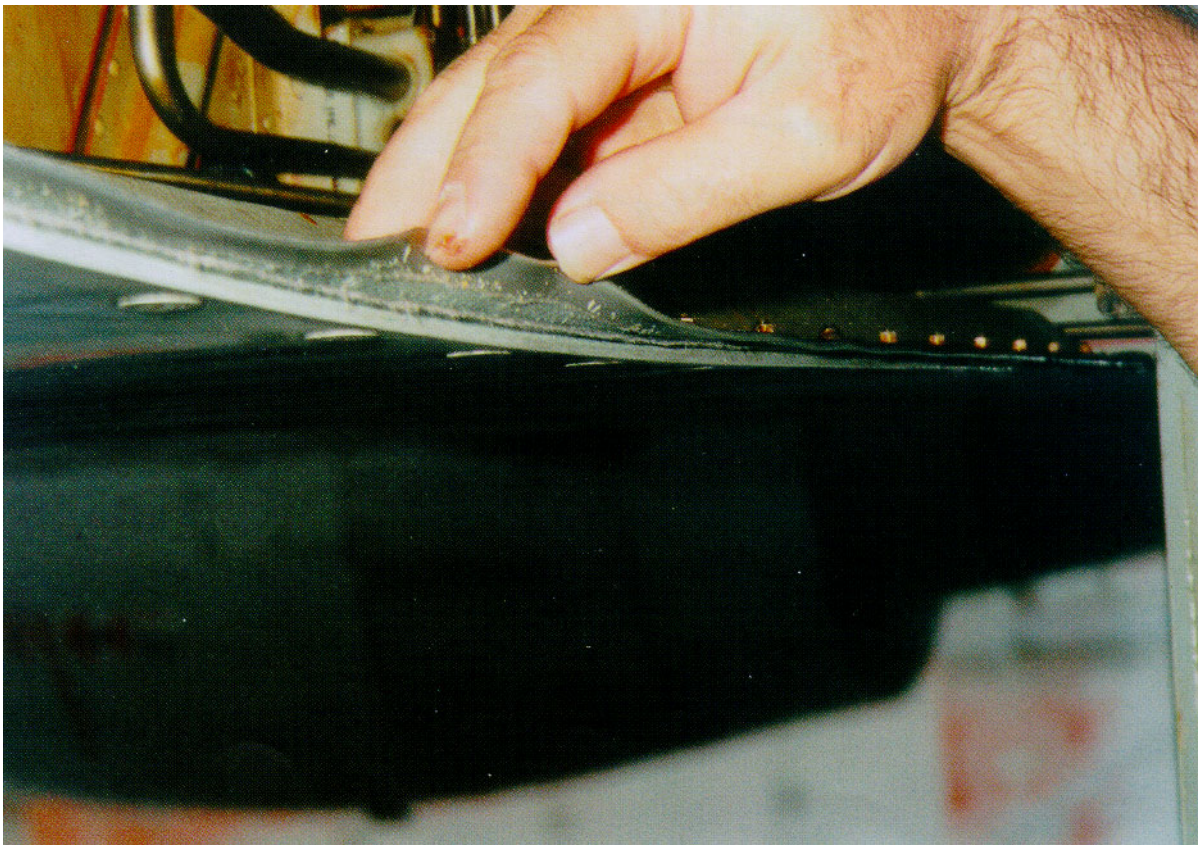


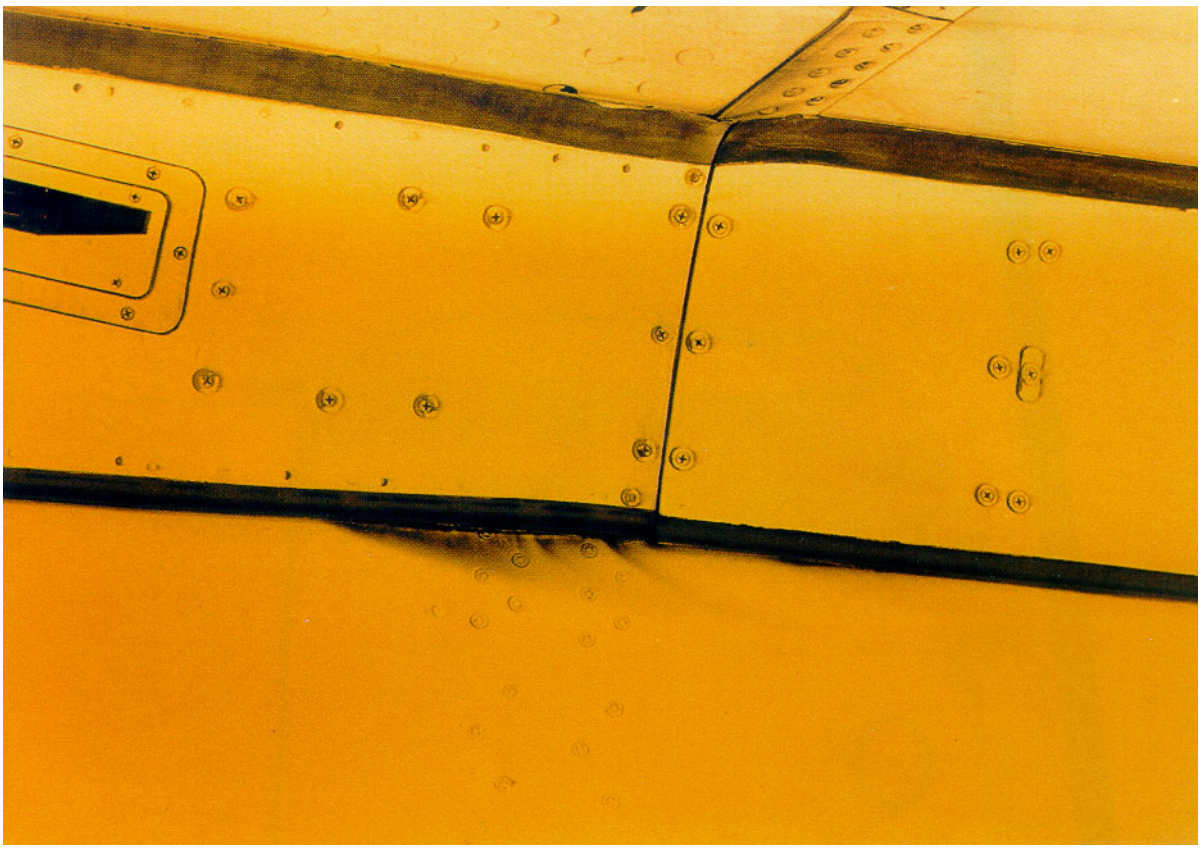
Damaged door



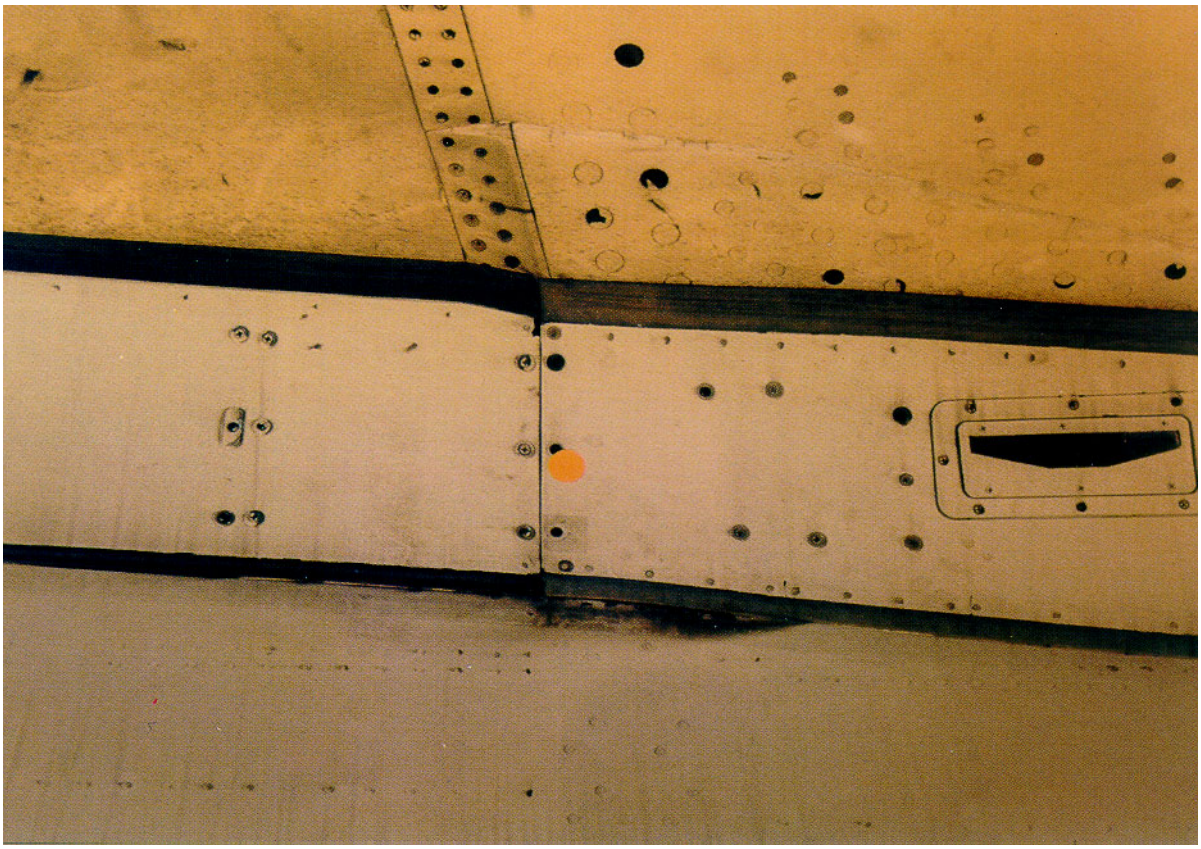


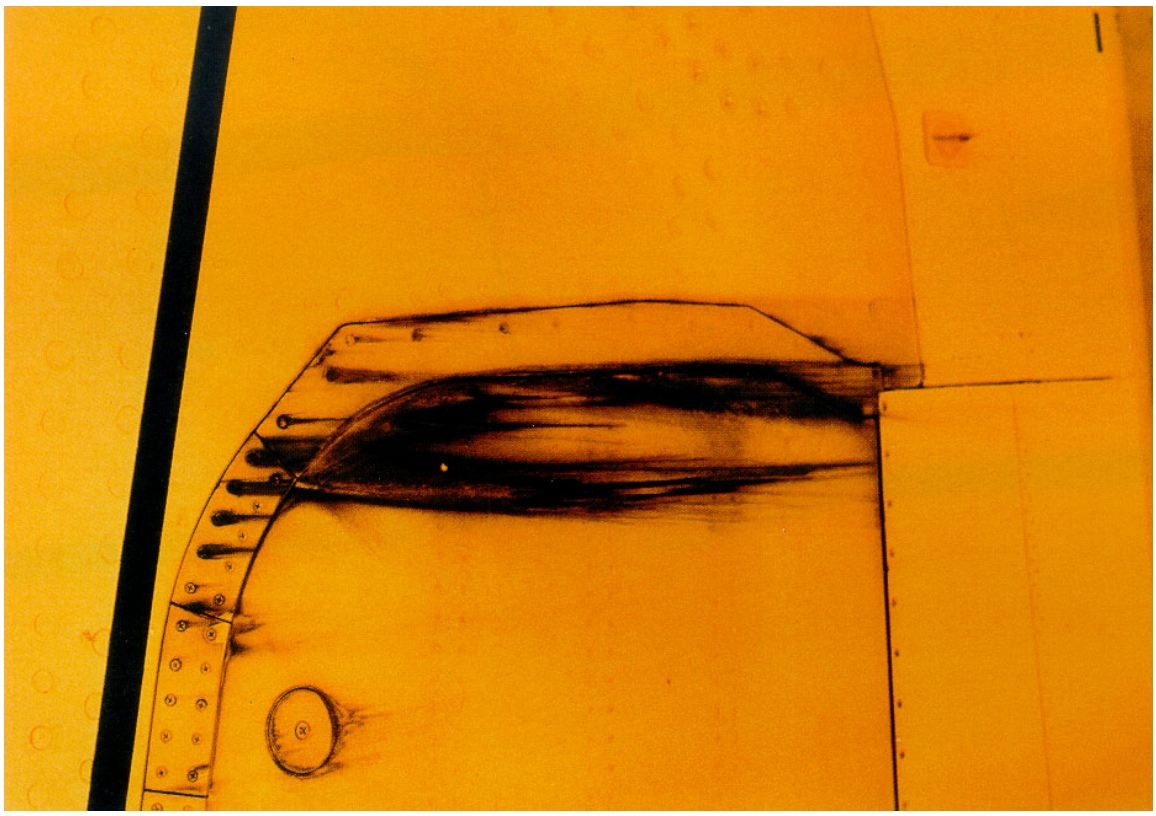
Damaged seal



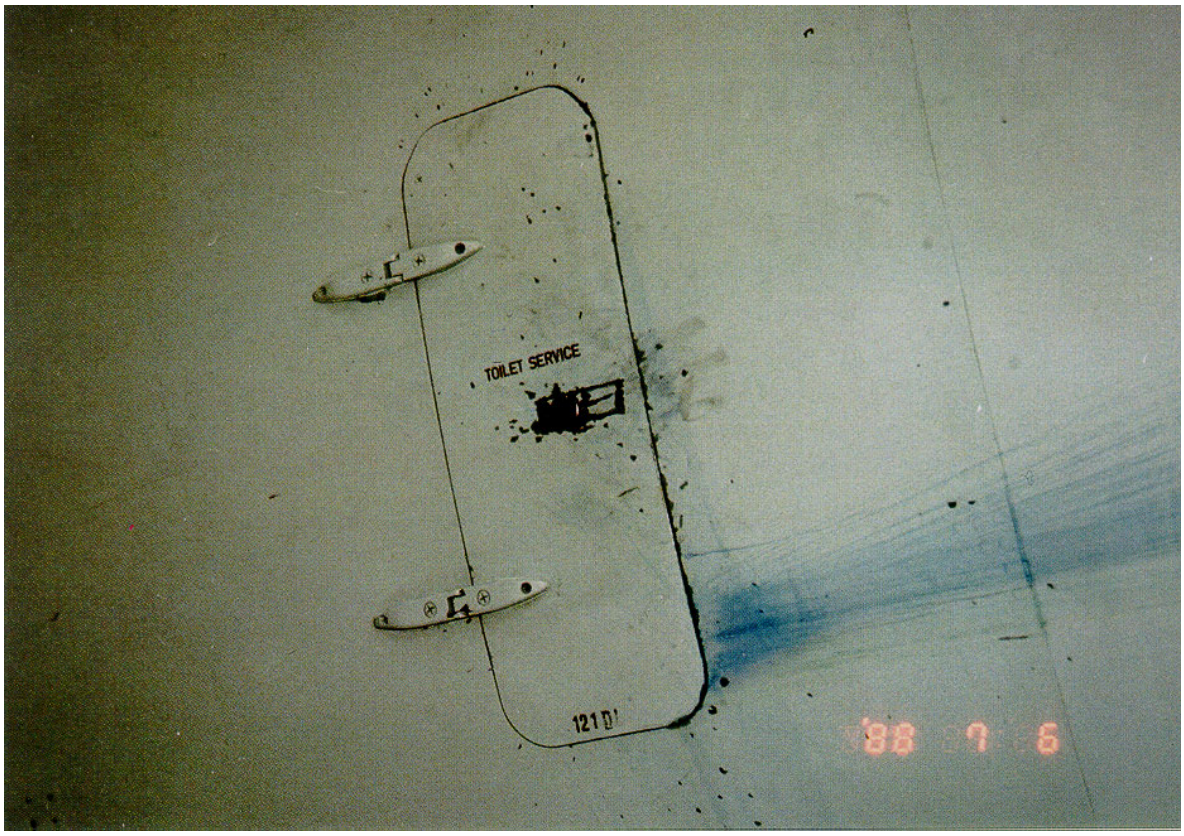


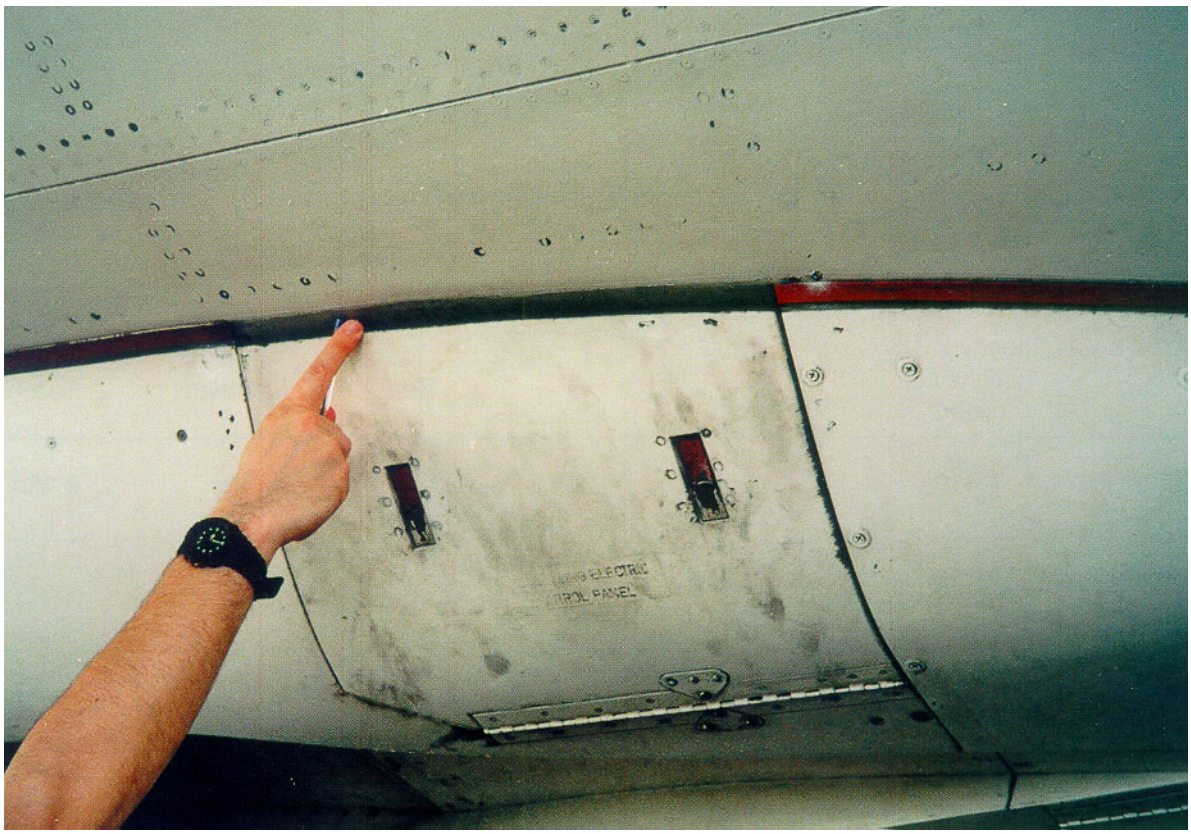
Damaged seals and leakage traces





Leakage traces due to damaged seal





Missing service door seal

3.6 Surface deterioration

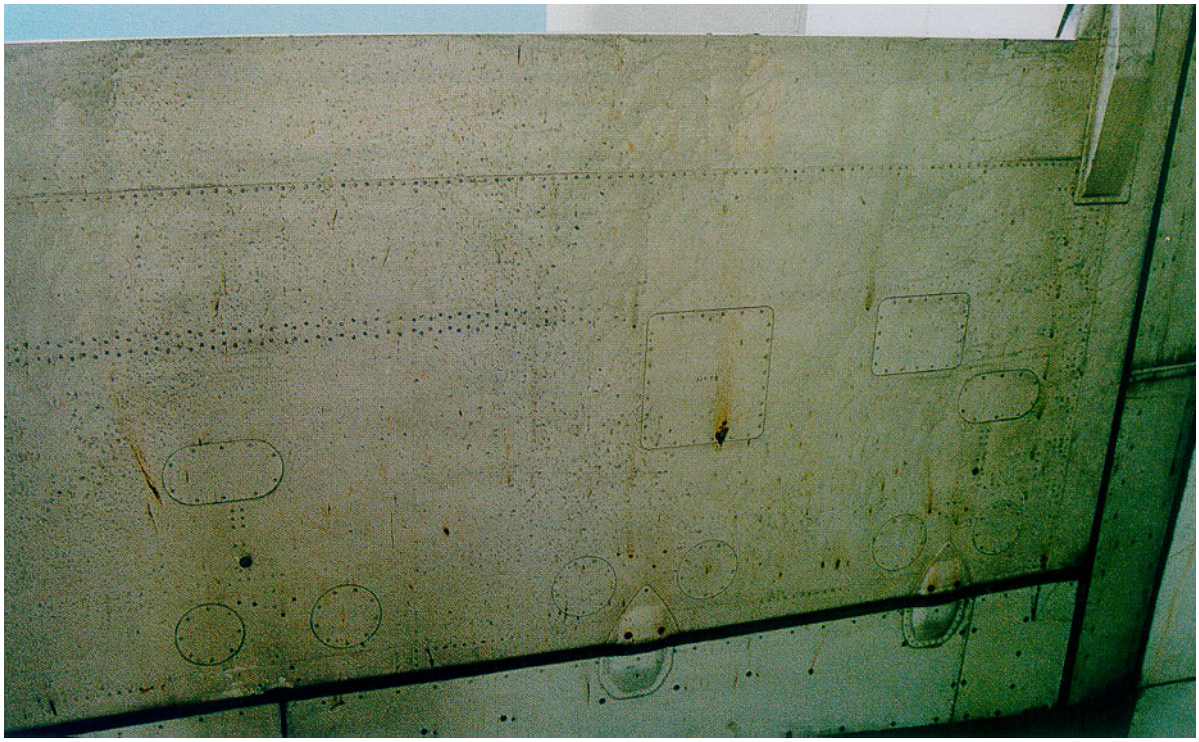
3.6.1 Skin roughness

Values are given for a 0.3mm skin roughness height over 1m^2 area in Zone 1.

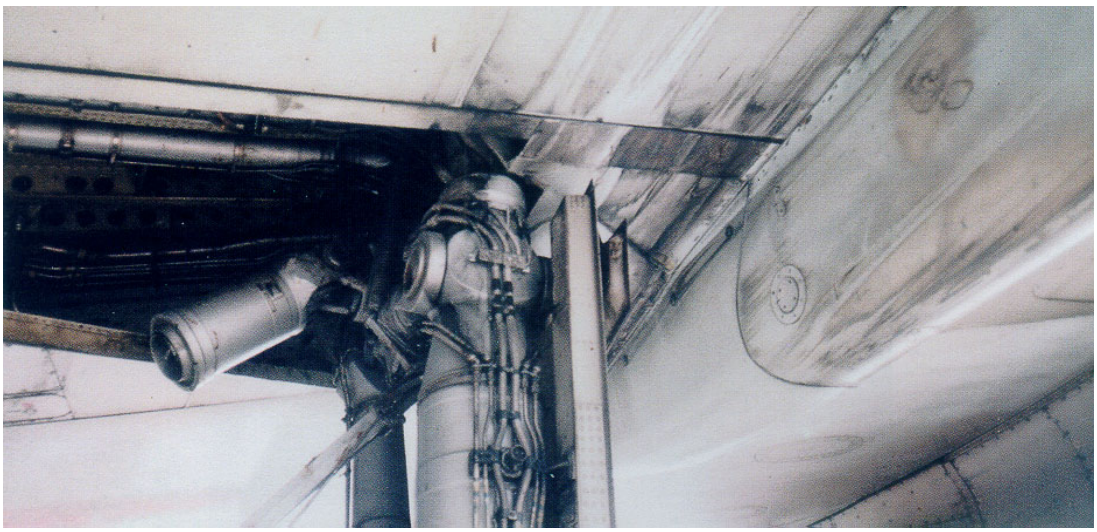
Affected area	Penalty in US gallons per year	**Penalty in US $ per year**	Maintenance reference	**Corrective action**		
				Men	Manhours	**Cost**
Leading edge slat	4,410	**$ 2,640**	Polishing of 1 sq.m. of surface SRM 51 41 10	1	3	**$ 150**
Wing skin – upper	2,720	**$ 1,630**				
Wing skin – lower	1,360	**$ 820**				
Tail	1,020	**$ 610**				
Fuselage	460	**$ 280**	Repainting the are AMM 51 12 00	1	8	**$ 400**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Roughness surface due to skydrol leakage on the belly fairing

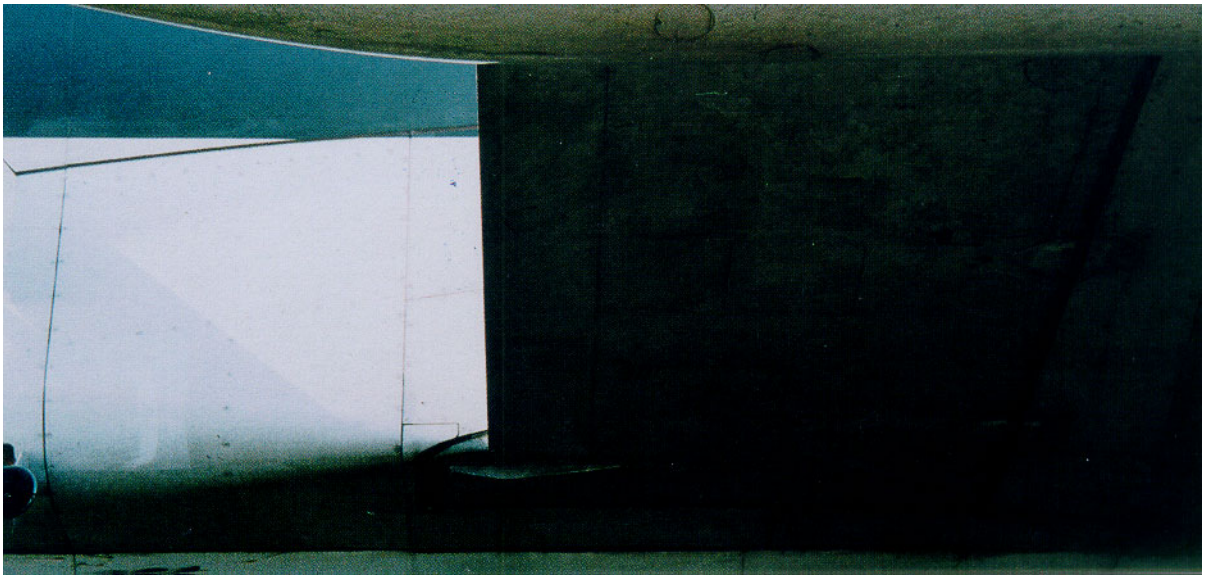


Skin roughness on lower-flap



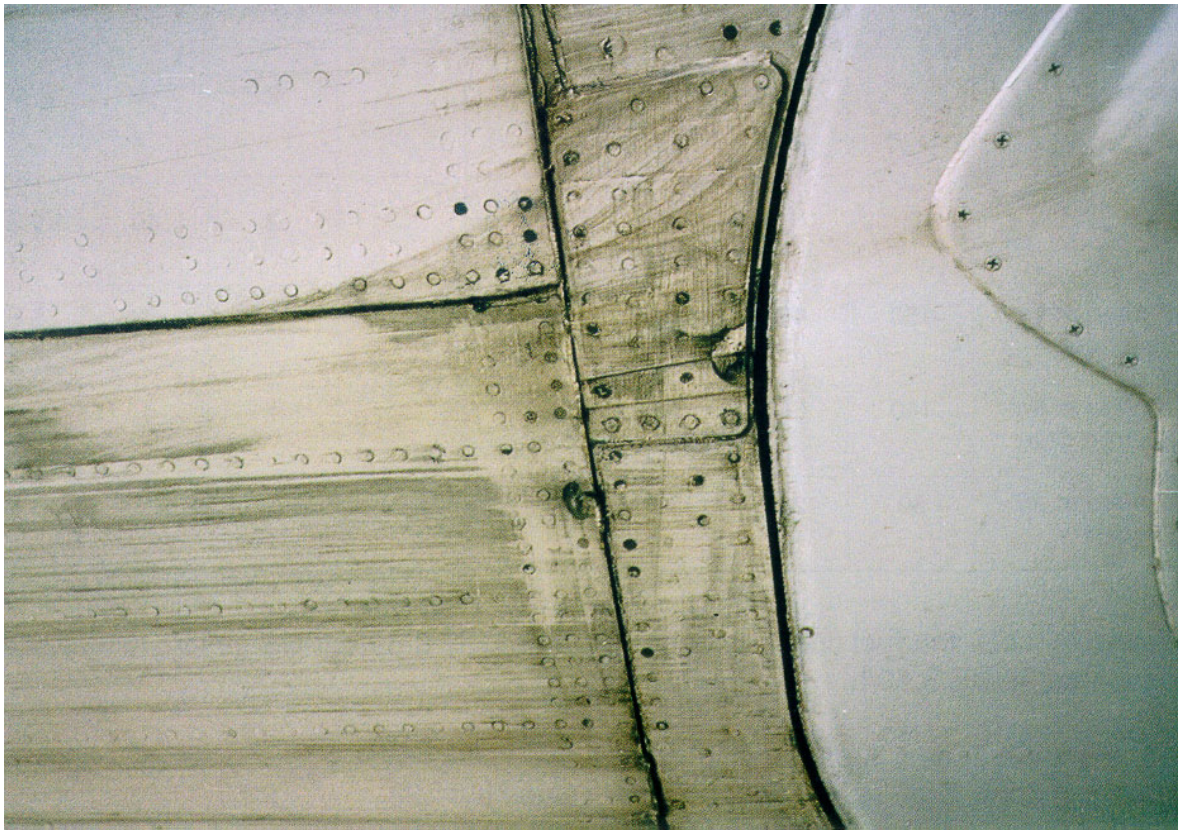
Dirt traces

Lower wing roughness



Lower flap track fairing roughness

Lower wing roughness



Leakage traces

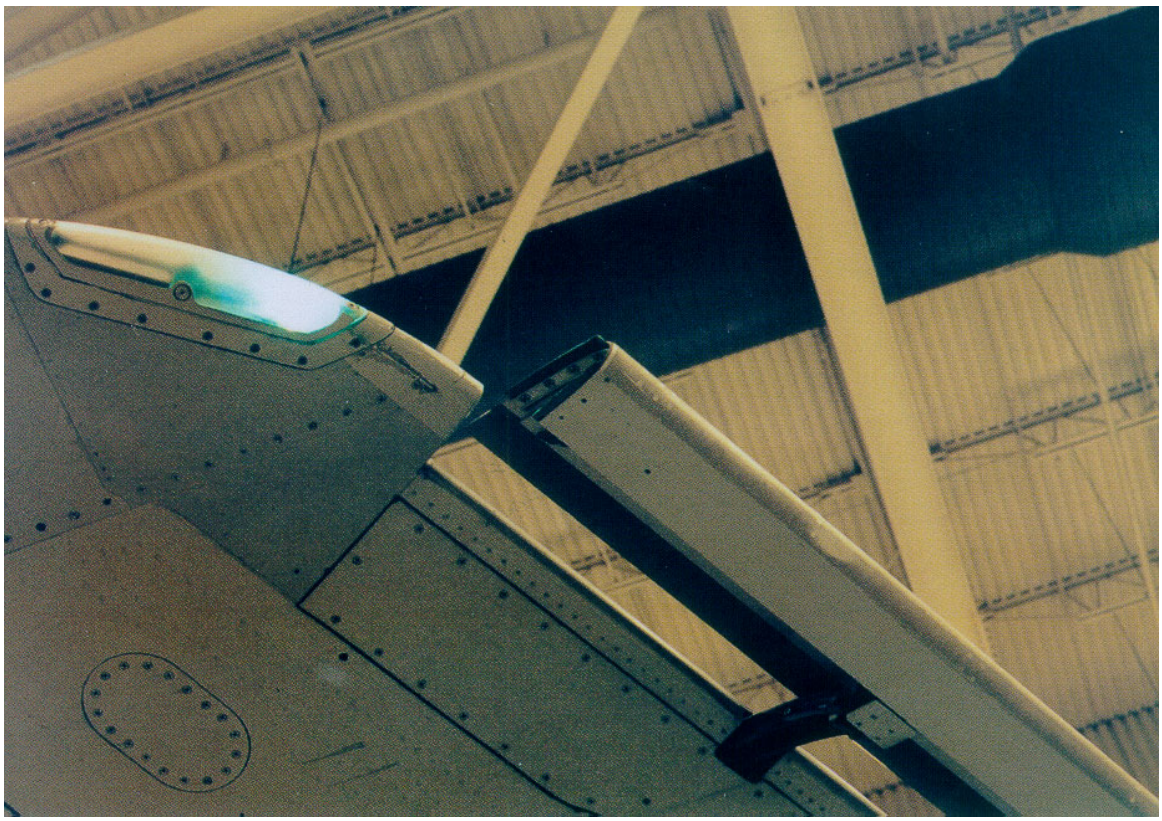
3.6.2 Skin dents

Values are given for a single dent or blister in specific areas.

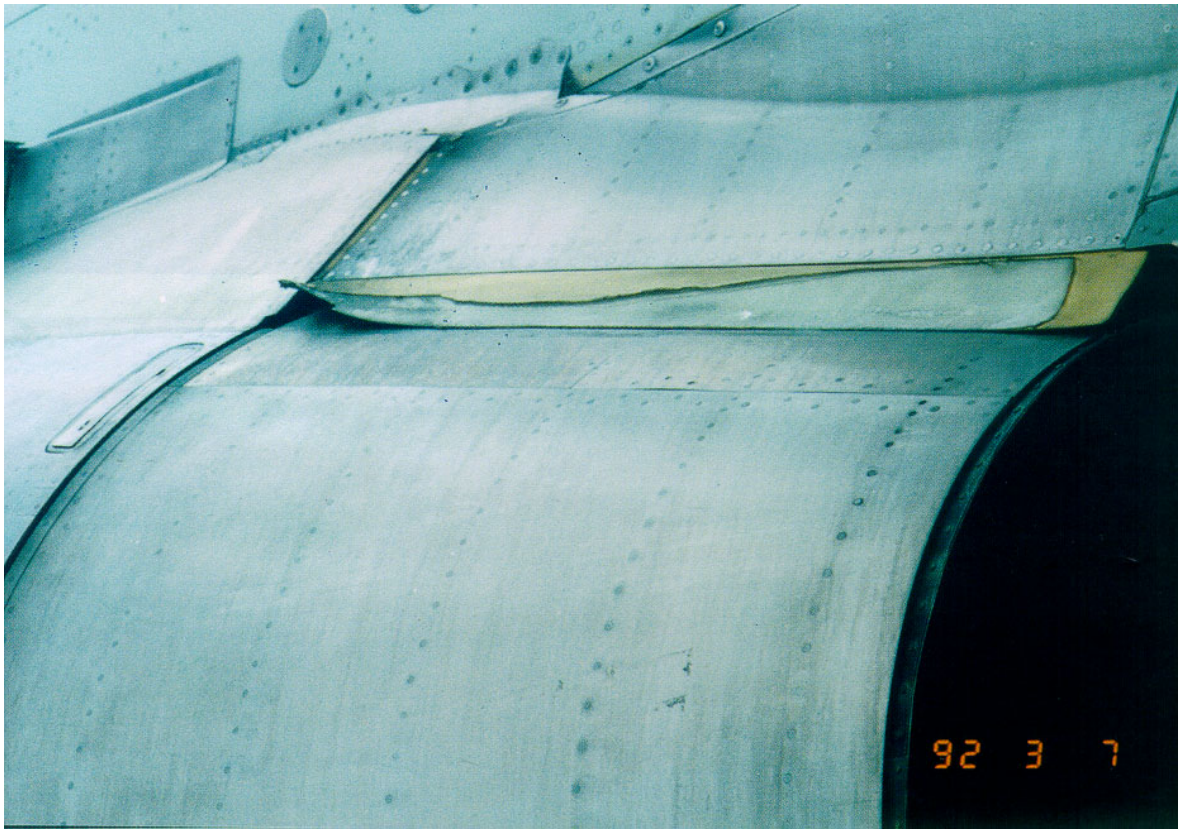
Affected area	Dent diameter / Surface area	Penalty in US gallons per year		Penalty in US $ per year		Maint. reference	Corrective action		
		5mm	10mm	5mm	10mm		Men	Manhours	Cost
Leading edge slat	20 m^2	36	36	$ 22	**$ 22**	SRM 57 00 00	2	24	**$ 1,200**
	80 m^2	159	173	$ 95	**$ 104**		2	60	**$ 3,000**
Wing (Zone 1)	20 m^2	22	22	$ 13	**$ 13**	SRM 57 00 00	2	24	**$ 1,200**
	80 m^2	98	107	$ 59	**$ 64**		2	60	**$ 3,000**
Tail (Zone 1)	20 m^2	7	15	$ 4	**$ 9**	SRM 55 00 00	2	24	**$ 1,200**
	80 m^2	14	29	$ 8	**$ 17**		2	40	**$ 2,000**
Fuselage (Zone 2)	20 m^2	3	7	$ 2	**$ 4**	SRM 53 00 00	2	16	**$ 800**
	80 m^2	7	13	$ 4	**$ 8**		2	40	**$ 2,000**
Scuff plate at forward pax door		150	400	$ 90	**$ 240**	SRM 53 42 11	1	1	**$ 50**
Scuff plate at forward cargo door		140	360	$ 80	**$ 220**	SRM 53 42 11	1	1	**$ 50**
Scuff plate at aft cargo door		80	220	$ 50	**$ 130**	SRM 53 42 11	1	1	**$ 50**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

For the fuselage Zone 1 areas, multiply the above values by 1.4
For the wing Zone 2 areas, divide the above values by 1.23
For the tail Zone 2 areas, divide the above values by 1.3

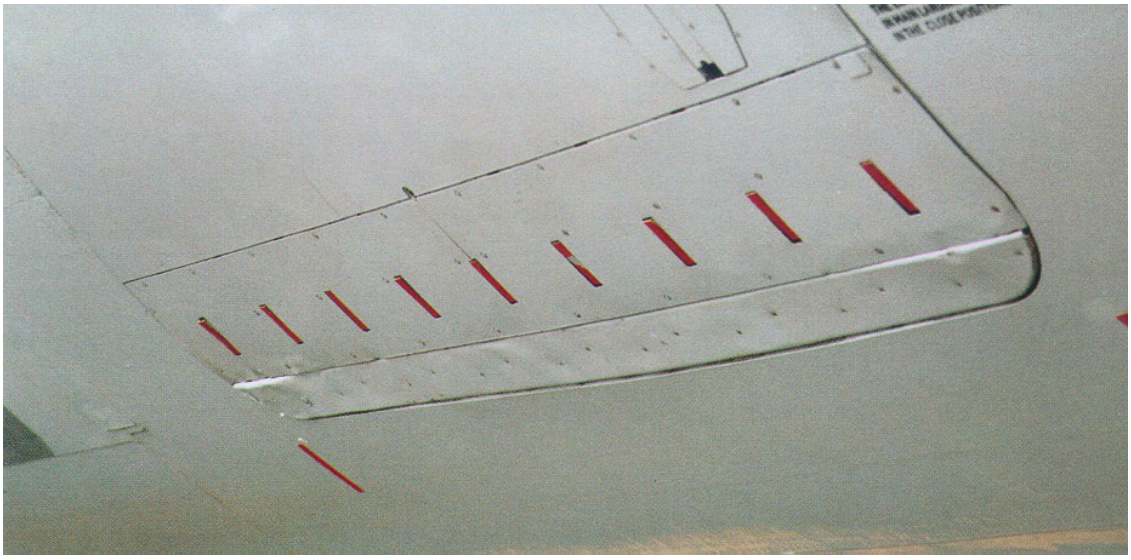


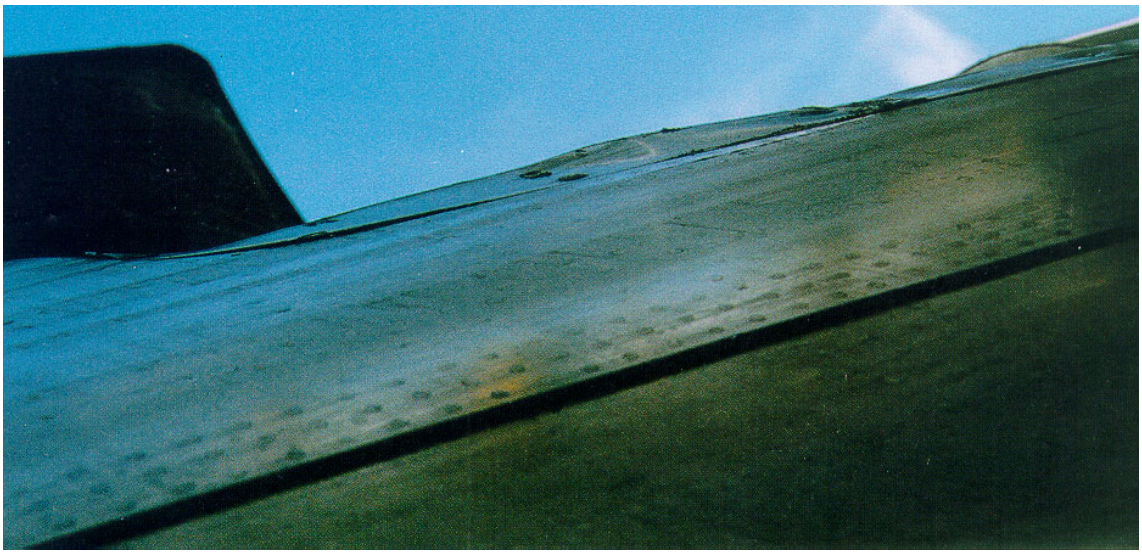
Dented slat



Dented engine cowl plate

Dented scuff plates



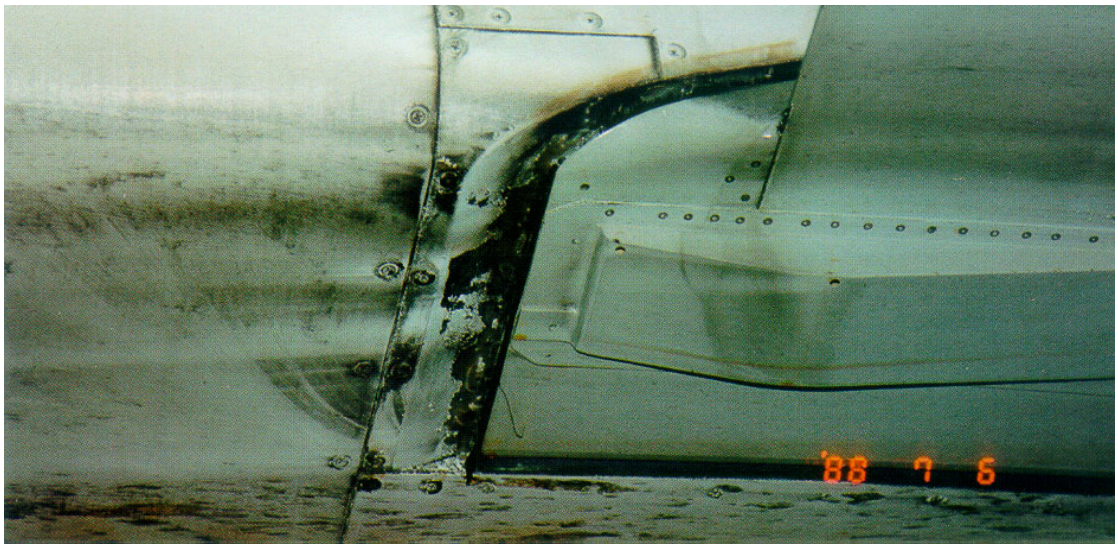


3.6.3 Unfilled butt joint gaps

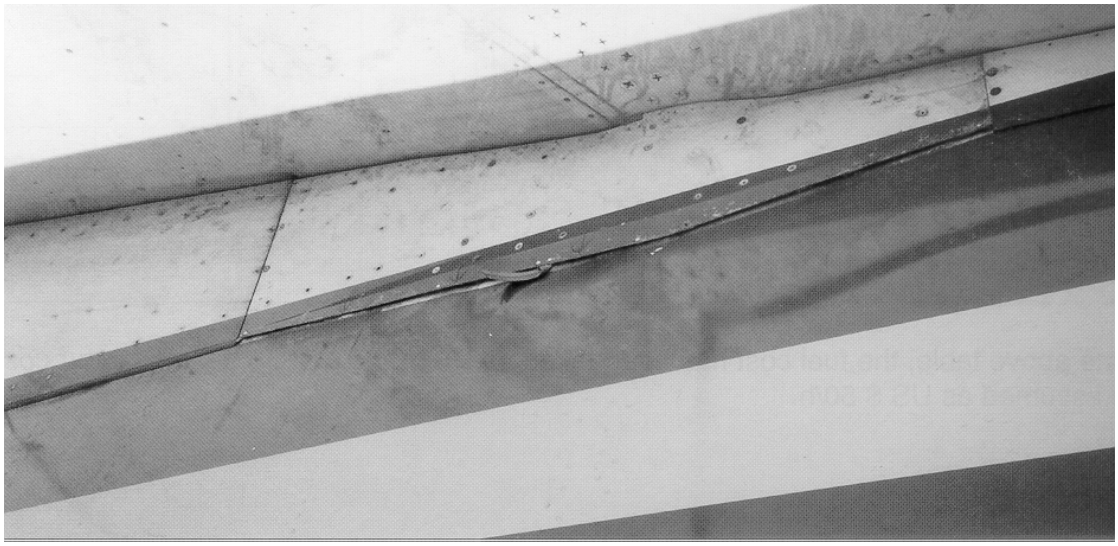
Values are given for a given step and per meter of sealant of gap 2mm and width 5mm.

Affected area	Penalty in US gallons per year		**Penalty in US $ per year**		Maint. reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Wing	29	23	**$ 17**	$ 14	SRM 51 40 20 AMM 51 20 00	1	2	**$ 100**
Tail	35	26	**$ 21**	$ 16	SRM 51 40 20 AMM 51 20 00	1	2	**$ 100**
Fuselage	24	15	**$ 14**	$ 9	SRM 51 40 20 AMM 51 20 00	1	2	**$ 100**

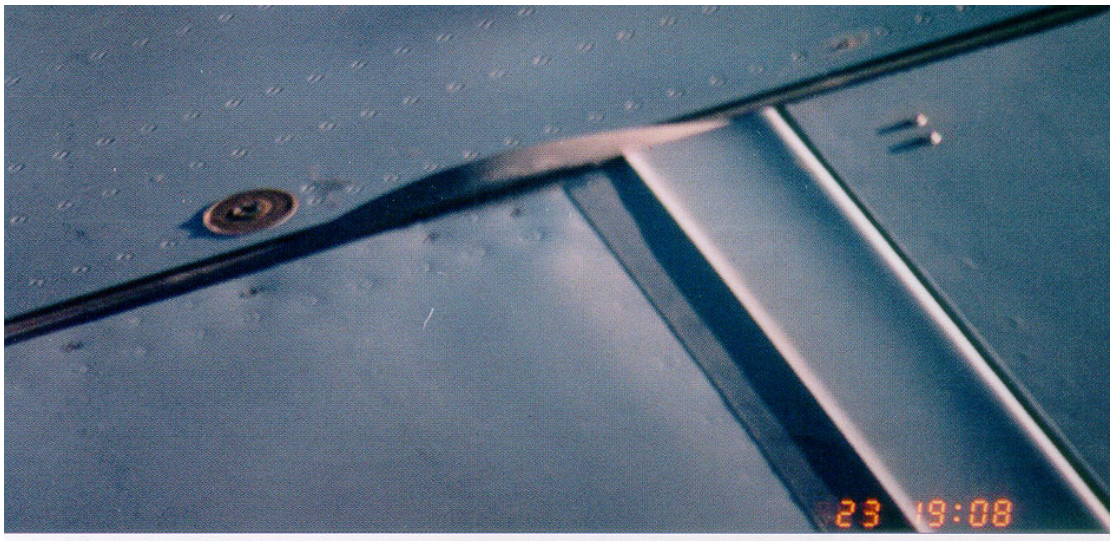
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.



Damaged seal



Missing seal



Missing seal

3.7 Consequences of hasty repairs

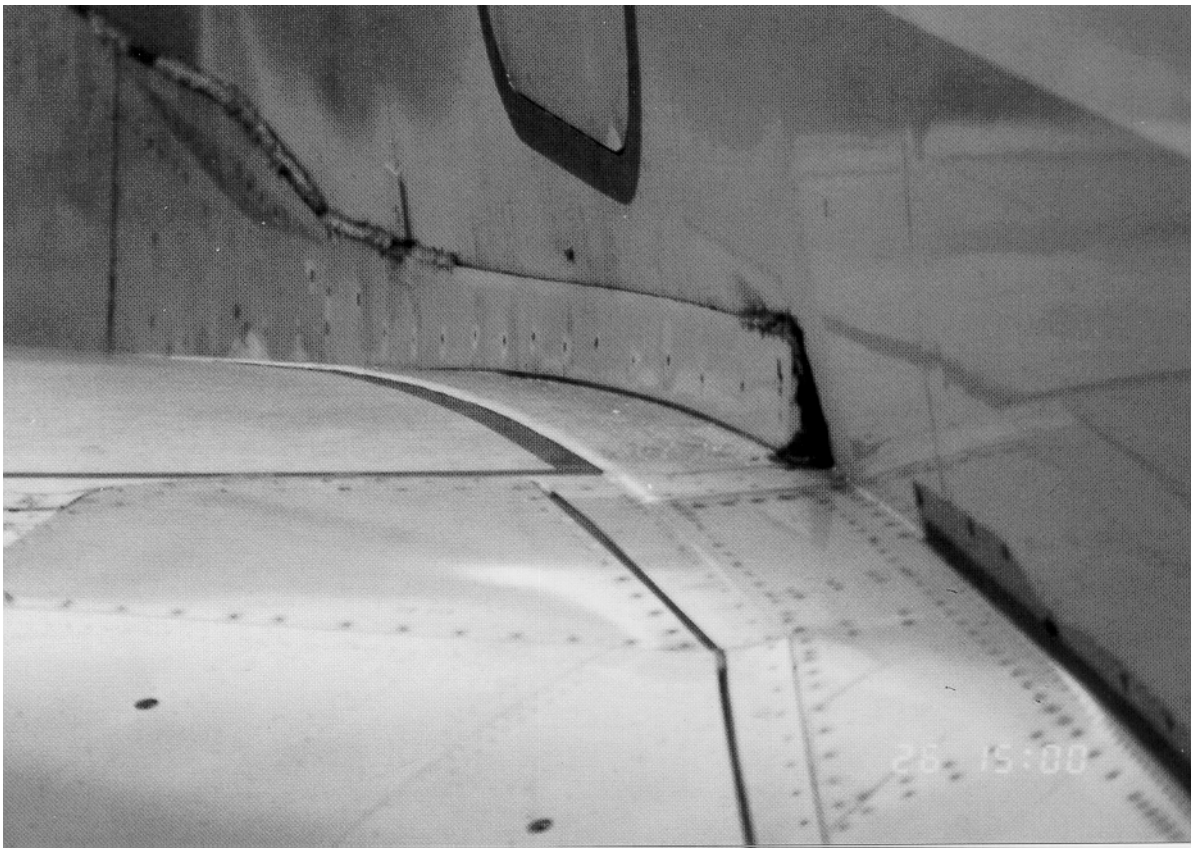
3.7.1 Overfilled butt joint gaps

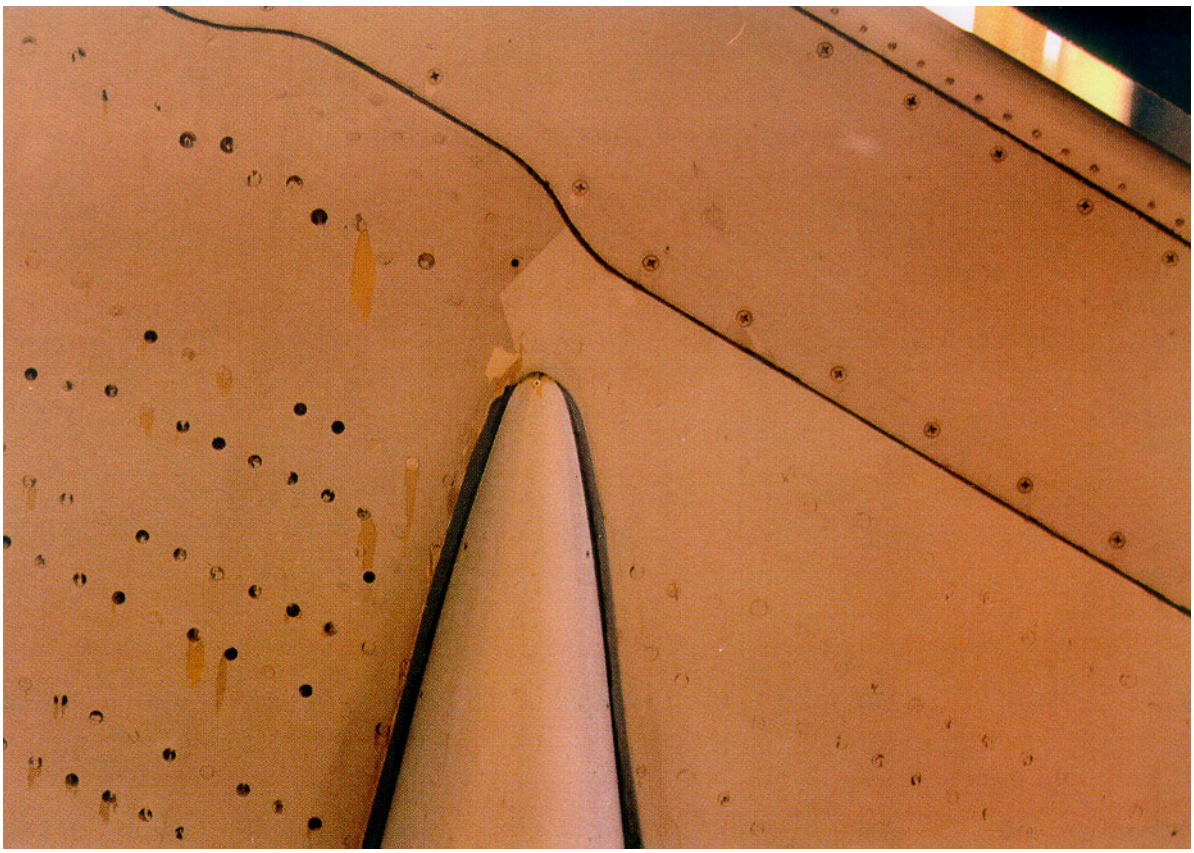
Values are given for a given step and per meter of sealant for overfilled butt joints of height 2 mm and width 5mm.

Sensitive area	Penalty in US gallons per year		**Penalty in US $ per year**		Maint. reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Leading edge slat	69	46	**$ 41**	$ 28	SRM 51 40 20 AMM 51 12 00	1	2	**$ 100**
Wing skin – upper	550	66	**$ 330**	$ 40		1	2	**$ 100**
Wing skin – lower	48	43	**$ 29**	$ 26		1	2	**$ 100**
Tail	70	50	**$ 40**	$ 30		1	2	**$ 100**
Fuselage	38	26	**$ 23**	$ 16		1	2	**$ 100**

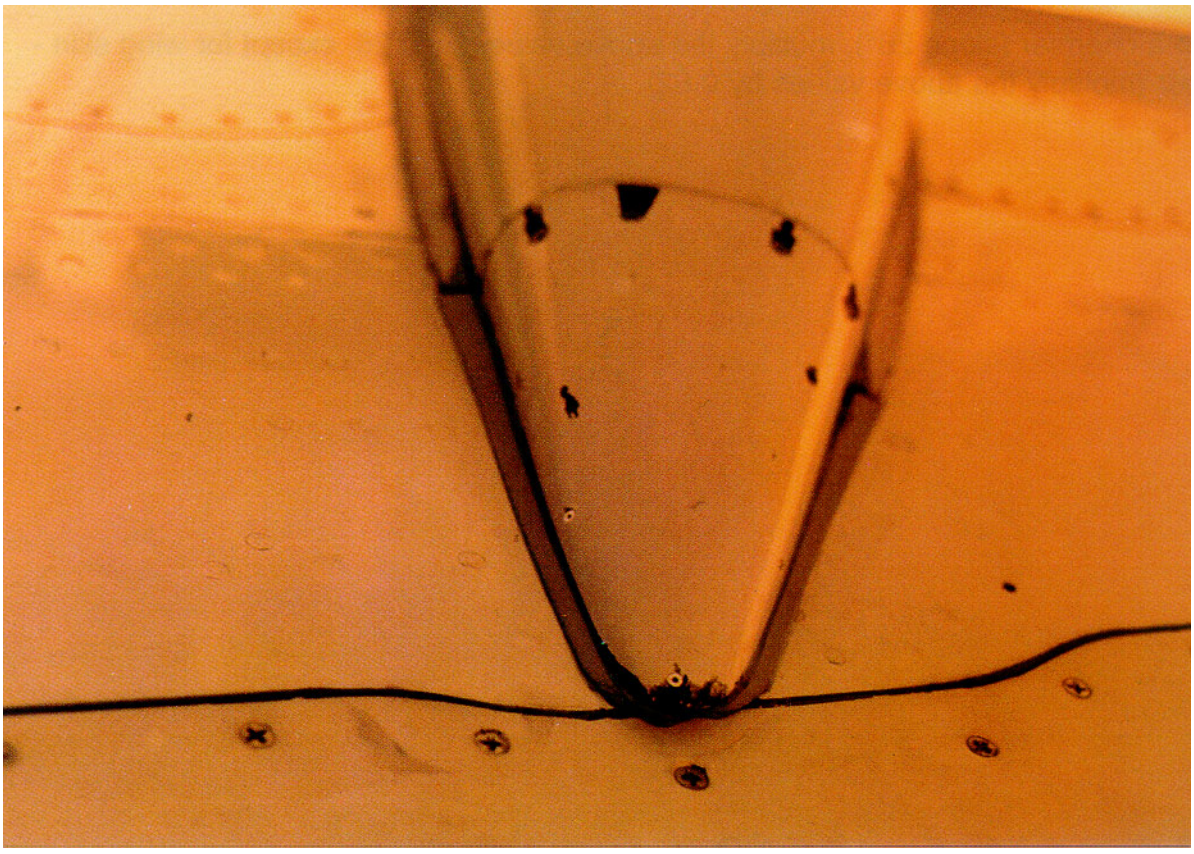
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Overfilled belly fairing butt joint gaps





Damaged seals



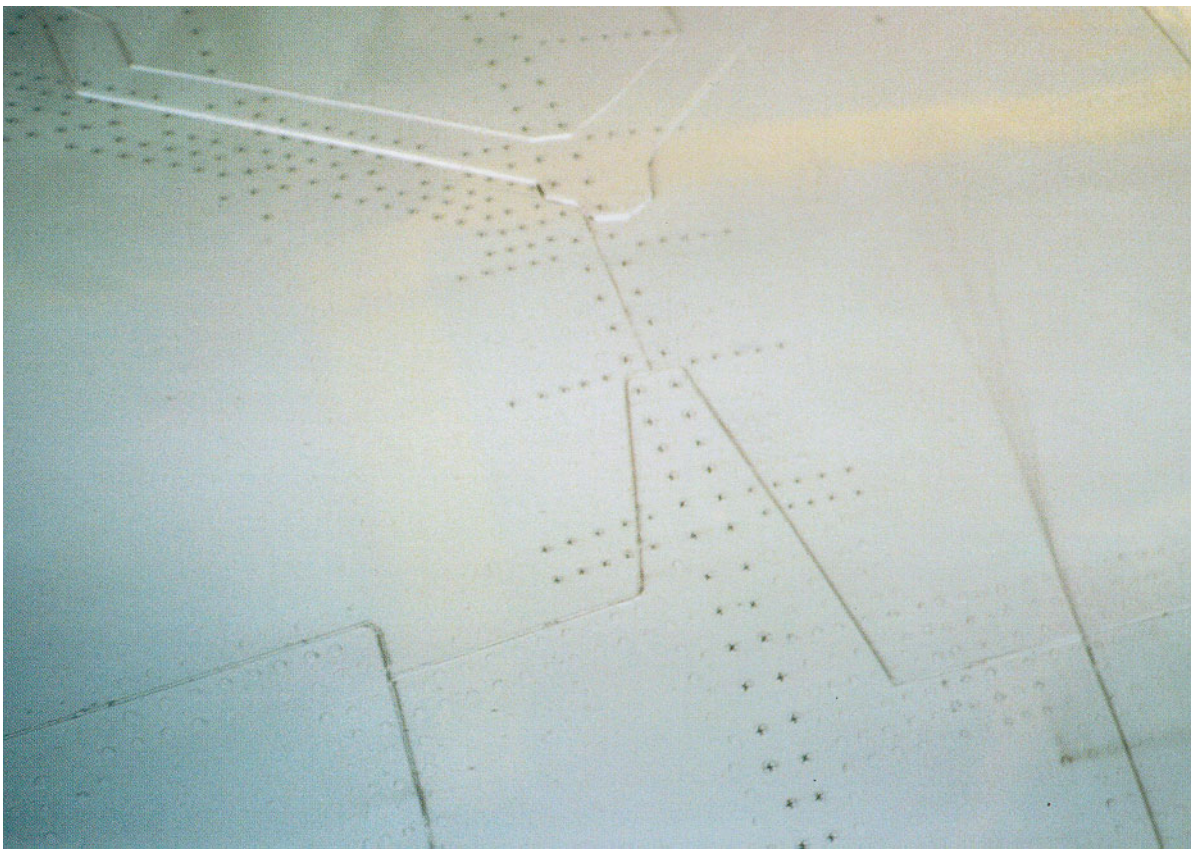
3.7.2 External patches

Values are given for a 1 m^2 patch of height 3 mm.

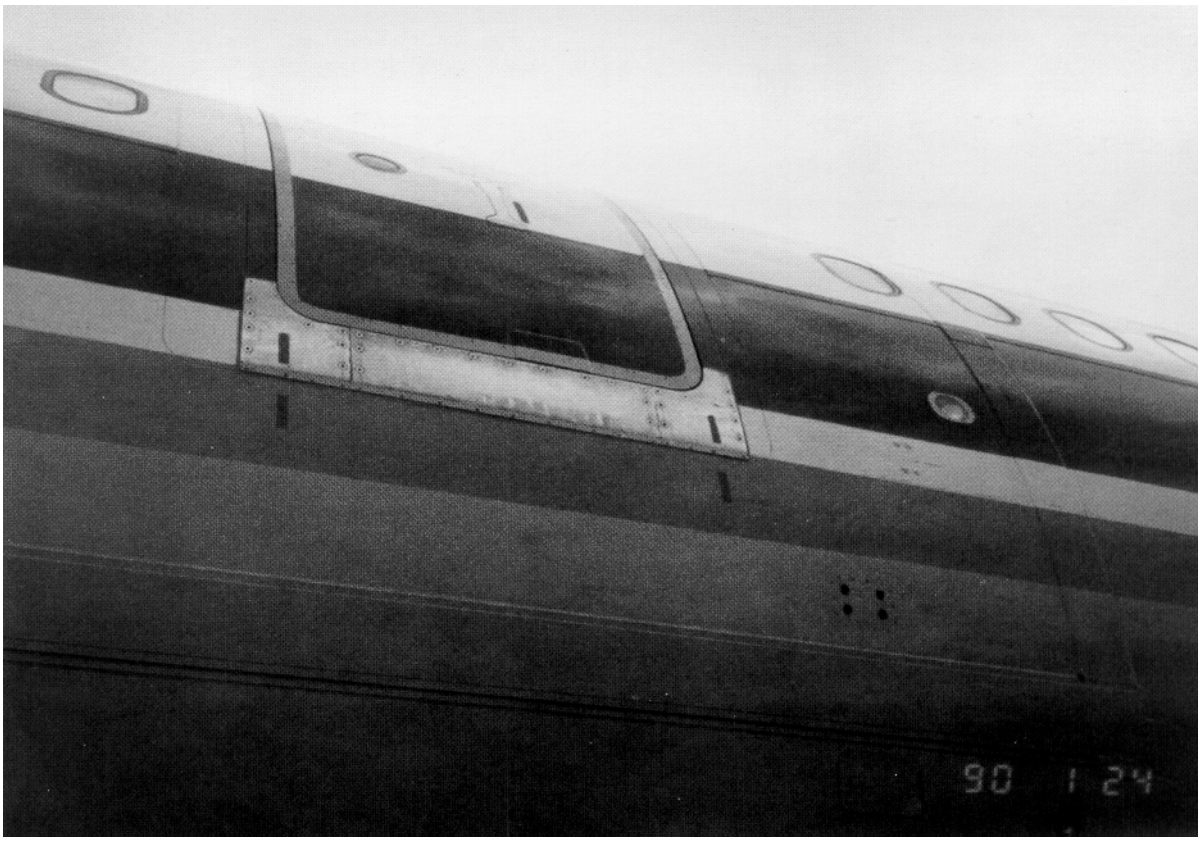
Sensitive area	Penalty in US gallons per year without chamfer		**Penalty in US $ per year**		Maint. reference	**Extra time for an internal patch instead of an external one**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Wing skin – upper	1,180	700	**$ 710**	$ 420	SRM 57 00 00	2	60	**$ 3,000**
Wing skin – lower	210	210	**$ 130**	$ 120	SRM 57 00 00	2	60	**$ 3,000**
Tail	520	340	**$ 310**	$ 200	SRM 55 00 00	2	40	**$ 2,000**
Fuselage	310	220	**$ 190**	$ 130	SRM 53 00 00	2	40	**$ 2,000**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

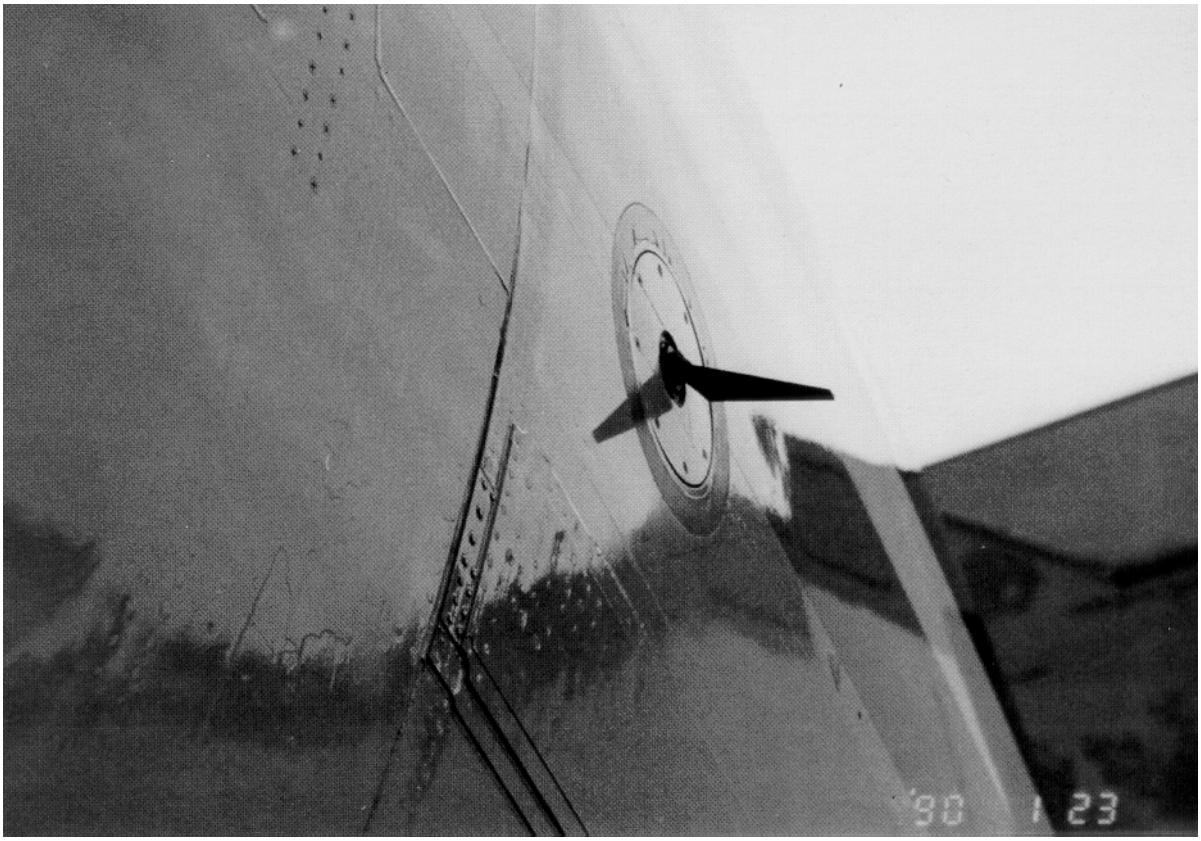
With a chamfer (slope 26°), multiply the above values by 0.28, except for wing skin – upper (multiply the above values by 0.82).



External patches on the fuselage



External patches on the fuselage



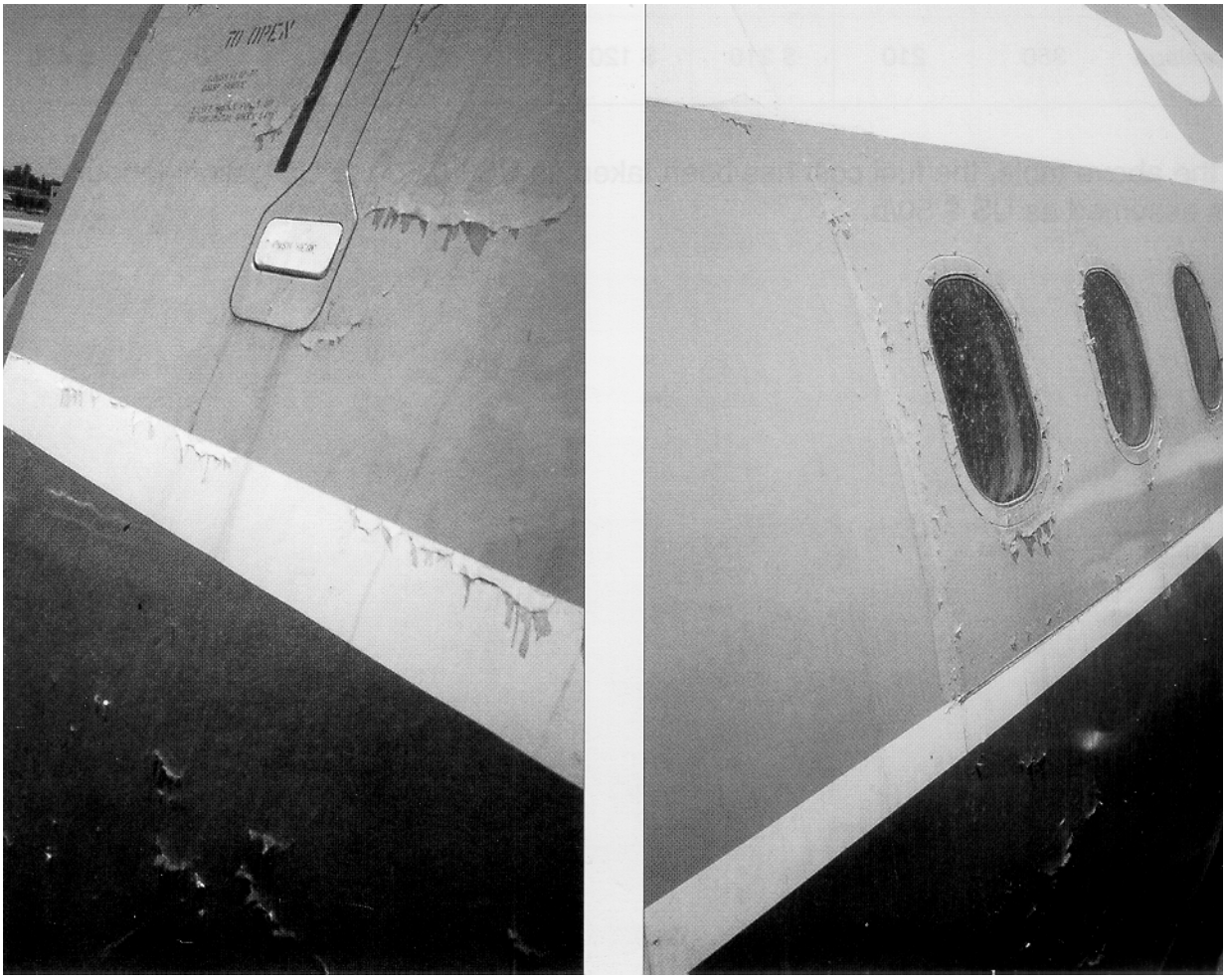
3.7.3 Paint peeling

Values are given for a high-density paint peeling over a 1 m^2 area.

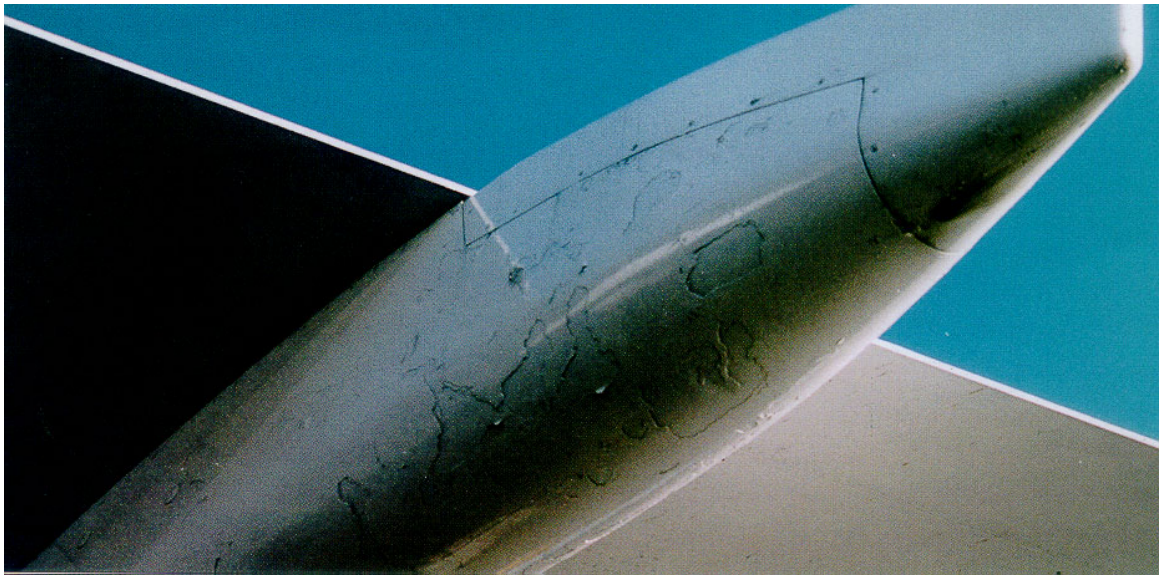
Sensitive area	Penalty in US gallons per year		**Penalty in US$ per year**		Maint. reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Leading edge slat	2,550	1,570	**$ 1,530**	$ 940	Repainting the area SRM 51 41 10 AMM 51 12 00	1	8	**$ 400**
Wing skin – upper	1,590	980	**$ 950**	$ 590		1	8	**$ 400**
Wing skin – lower	640	640	**$ 390**	$ 390		1	8	**$ 400**
Tail	540	400	**$ 330**	$ 240		1	8	**$ 400**
Fuselage	350	210	**$ 210**	$ 120		1	8	**$ 400**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

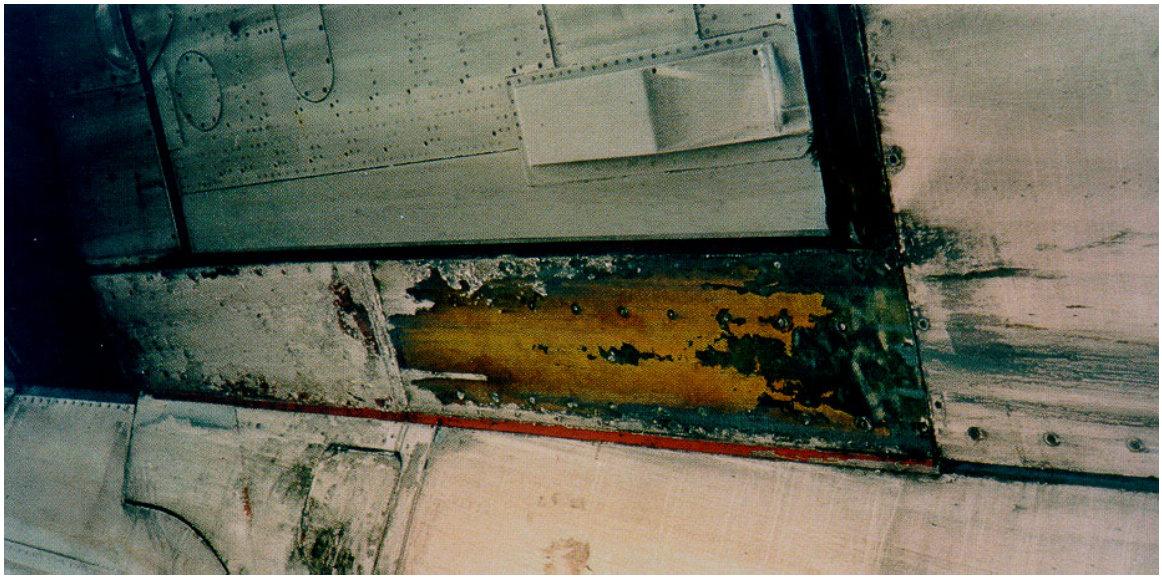
Paint peeling

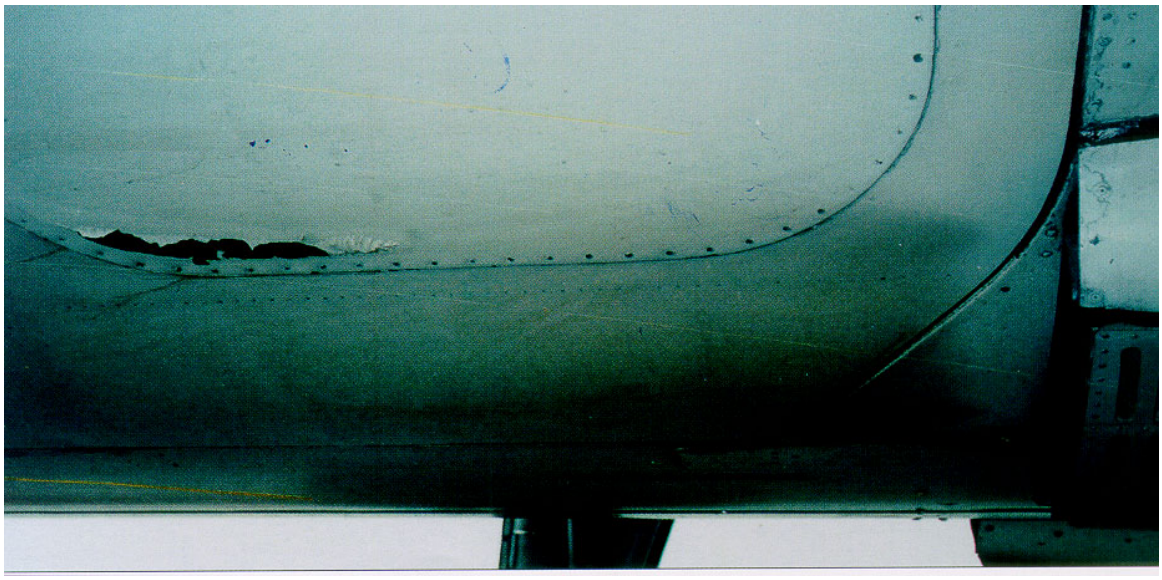


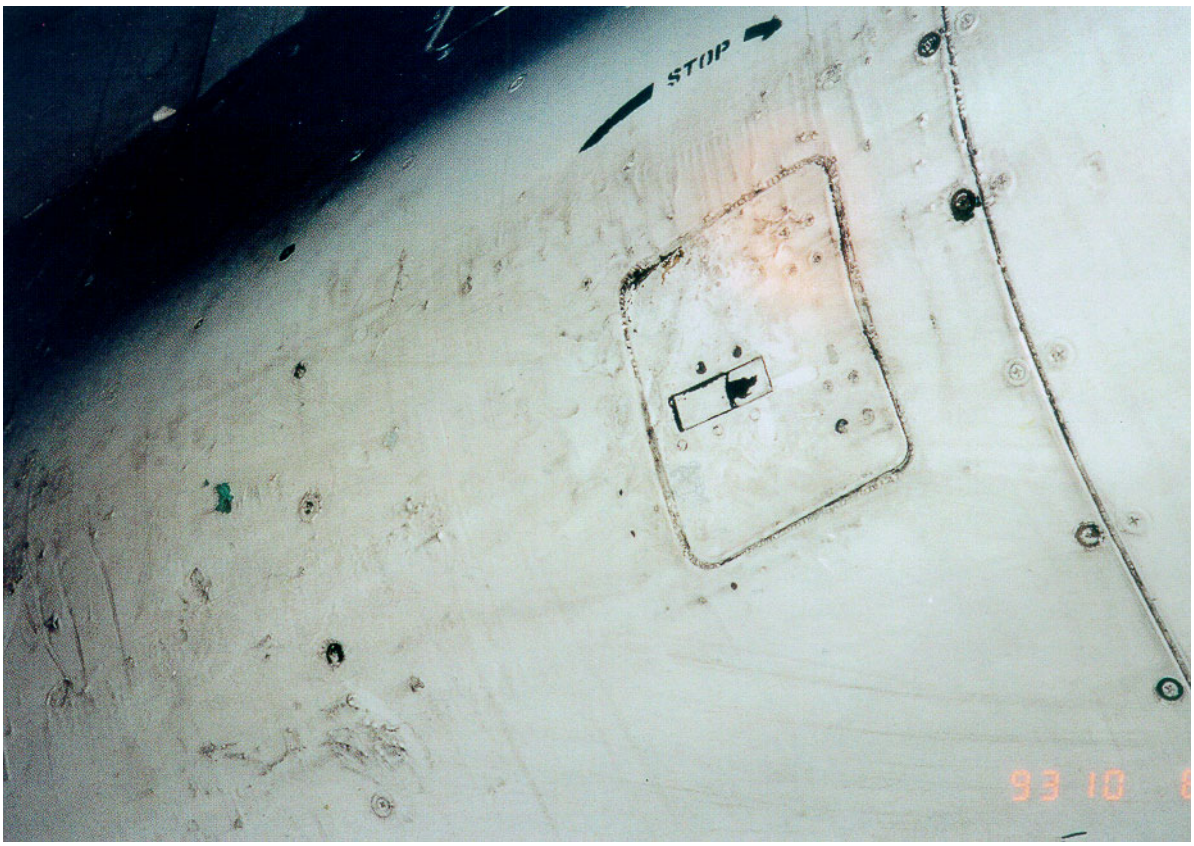
Paint peeling



Paint peeling







Paint peeling

4. A319/A320/A321 FAMILY

4. A319/A320/A321 FAMILY

The three aircraft of the narrow-body family have very similar airframes. Values given are best estimates for each aircraft.

As a simple rule, the higher the flight hours, the greater the effect of aerodynamic deterioration on fuel consumption. For that reason, assumptions about flight hours per year are very important and can cause very considerable differences, depending on each individual case. Based on data reported by all Airbus operators, 2,700 flight hours per year per aircraft were assumed for the A320 family.

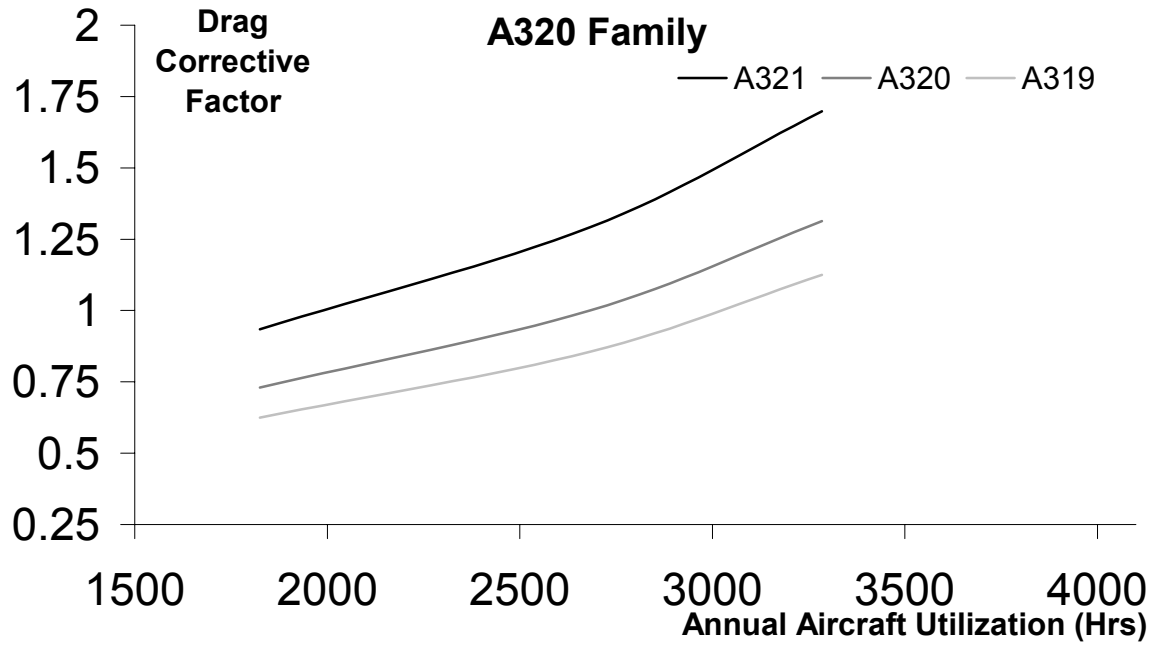
Drag penalty values for each item are given in the tables from pages 80 to 110, and correspond to the A320. These values could be considered valid for the A319 and the A321.

Manhours requested for each item are given as a guideline and should be a good average for the whole narrow-body family (A319/A320/A321).

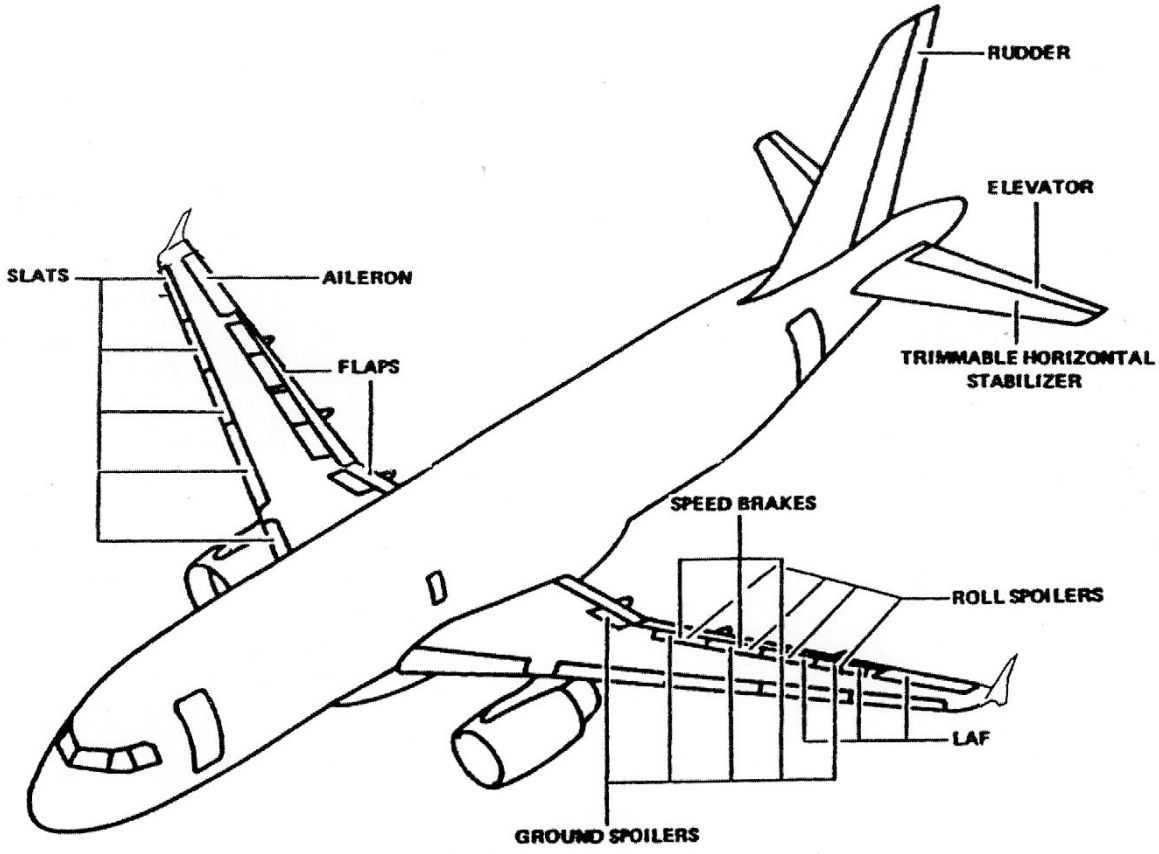
The accuracy of the given values is high enough to allow a comparison between the fuel burn penalties and associated maintenance costs.

Corrective factor for drag penalty

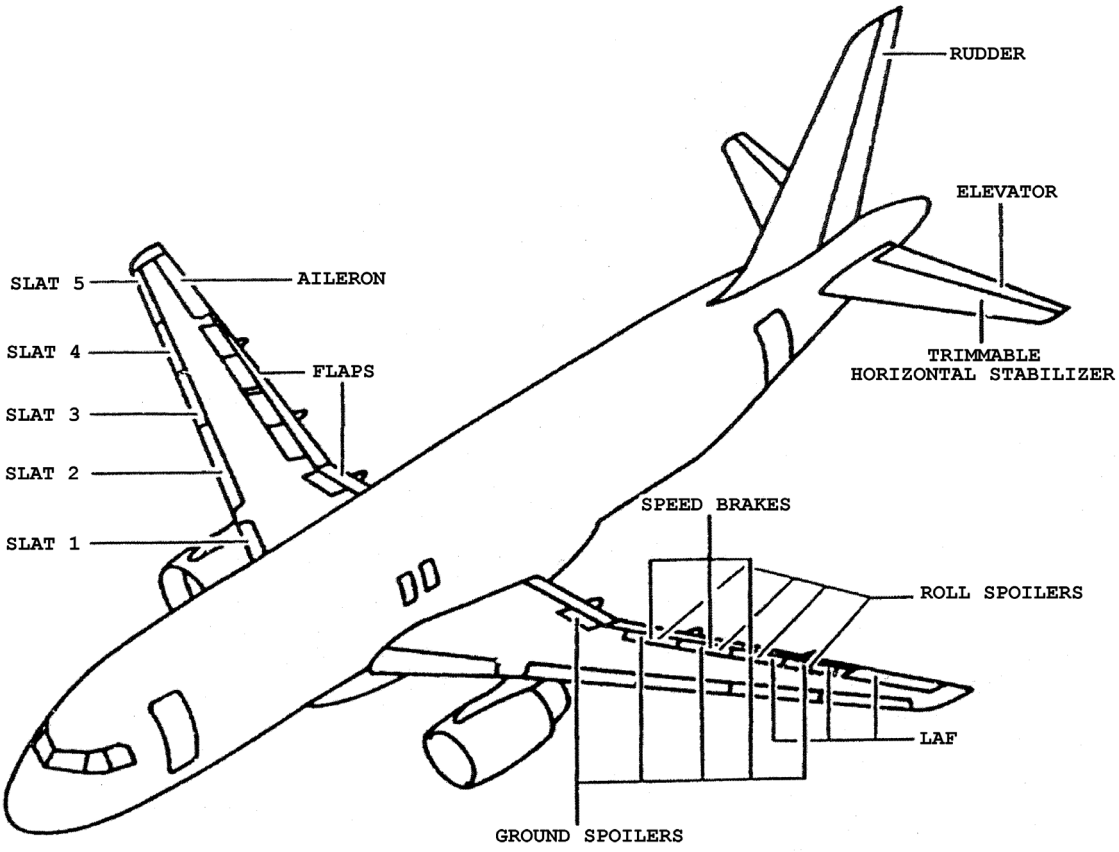
If there is a need to determine aircraft fuel penalties with greater accuracy and/or if the airline has a different aircraft utilisation, corrective factors to apply to the yearly fuel penalty (in US gallons or US$) can be introduced in relation to the annual aircraft utilisation. This corrective factor introduces as well the geometrical differences.



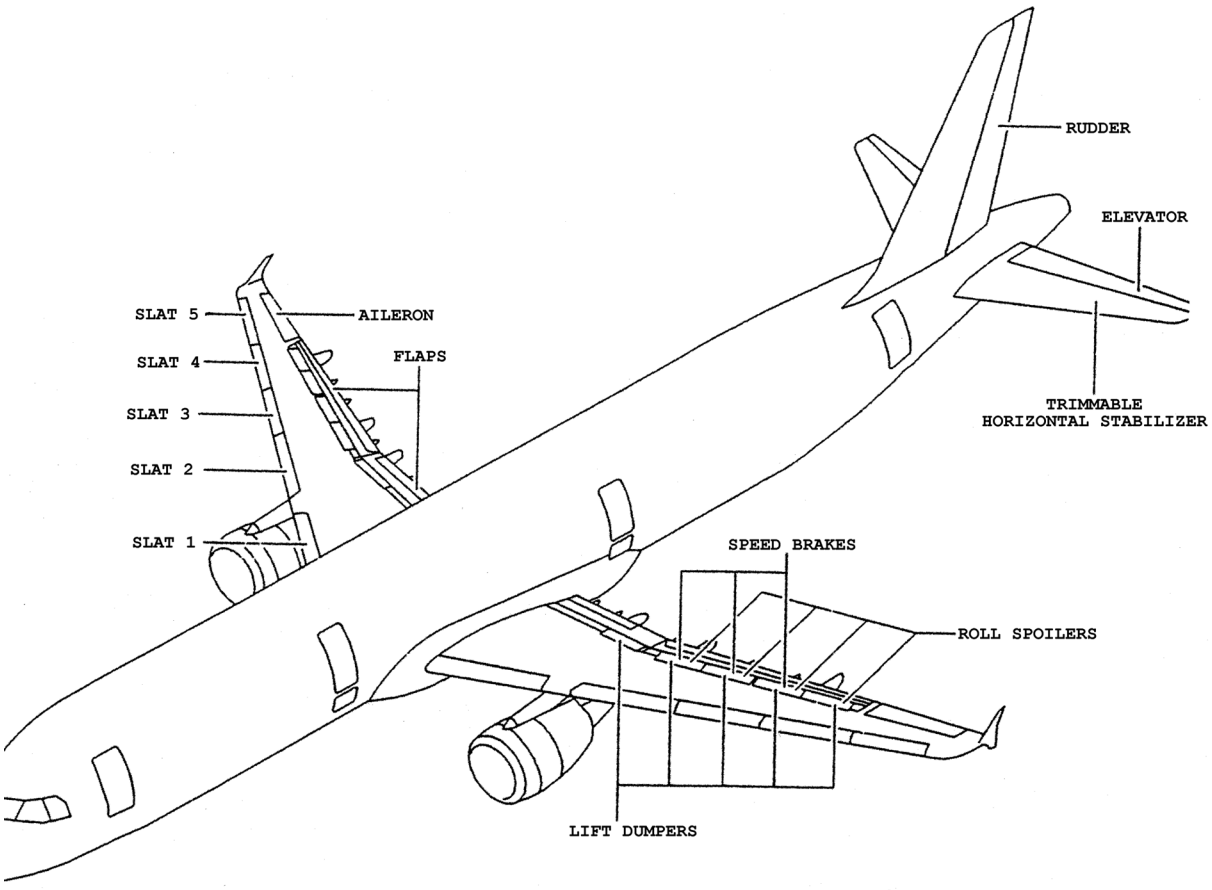
A319


RUDDER
ELEVATOR
SLATS
AILERON
FLAPS
TRIMMABLE HORIZONTAL STABILIZER
SPEED BRAKES
ROLL SPOILERS
LAF
GROUND SPOILERS

A320


RUDDER
ELEVATOR
TRIMMABLE
HORIZONTAL STABILIZER
SLAT 5
AILERON
SLAT 4
FLAPS
SLAT 3
SLAT 2
SLAT 1
SPEED BRAKES
ROLL SPOILERS
LAF
GROUND SPOILERS

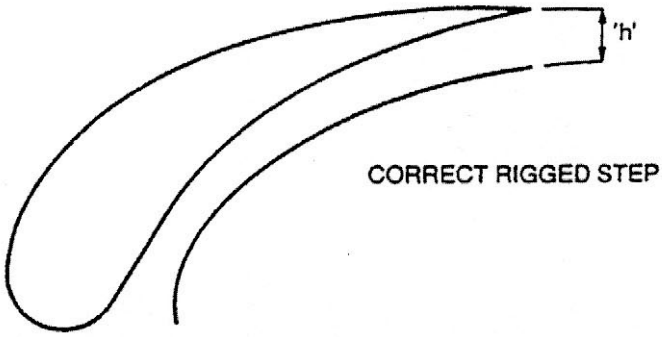
A321


RUDDER
ELEVATOR
SLAT 5
AILERON
SLAT 4
FLAPS
SLAT 3
SLAT 2
SLAT 1
TRIMMABLE
HORIZONTAL STABILIZER
SPEED BRAKES
ROLL SPOILERS
LIFT DUMPERS

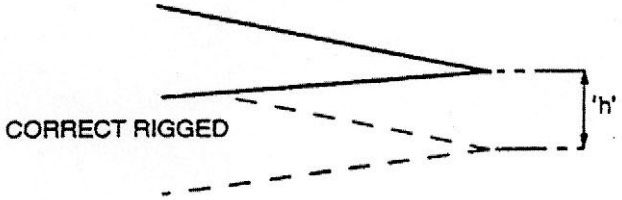
4.1 Misrigging of control surfaces

These items correspond to a specific control surface misrigging. The penalty is expressed by the difference in height at the control surface trailing edge between the misrigged and the correct position.

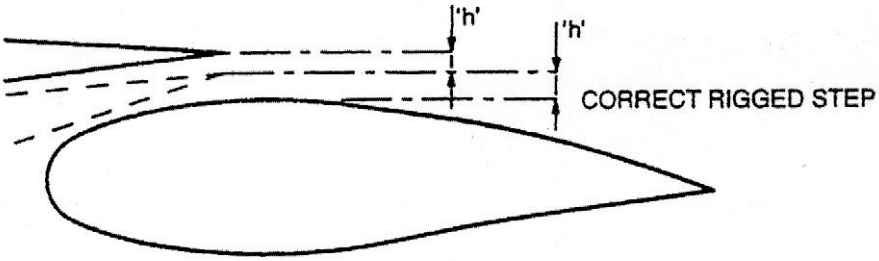
Slat



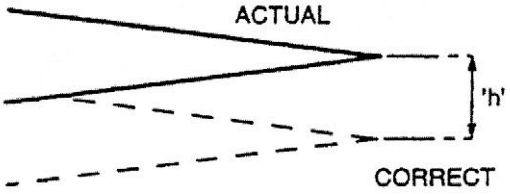
Flap



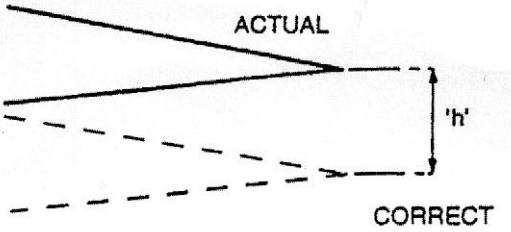
Spoiler



Aileron



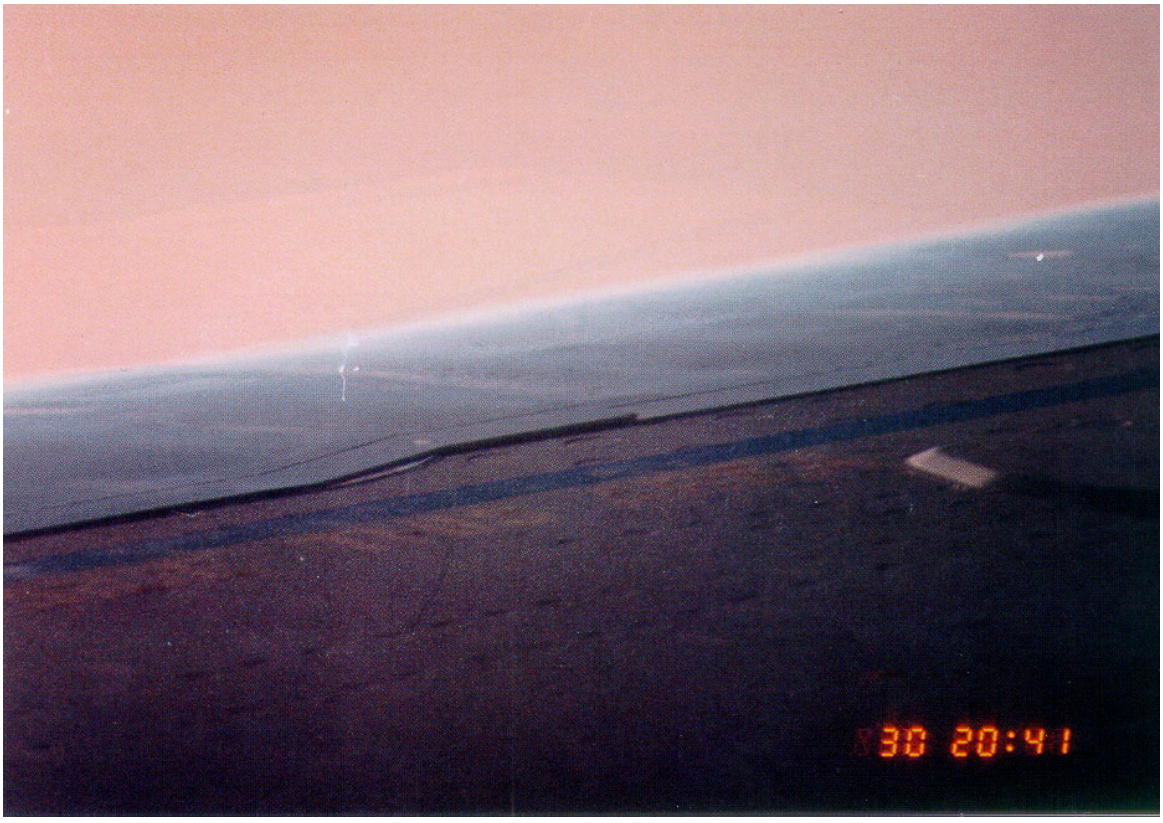
Rudder



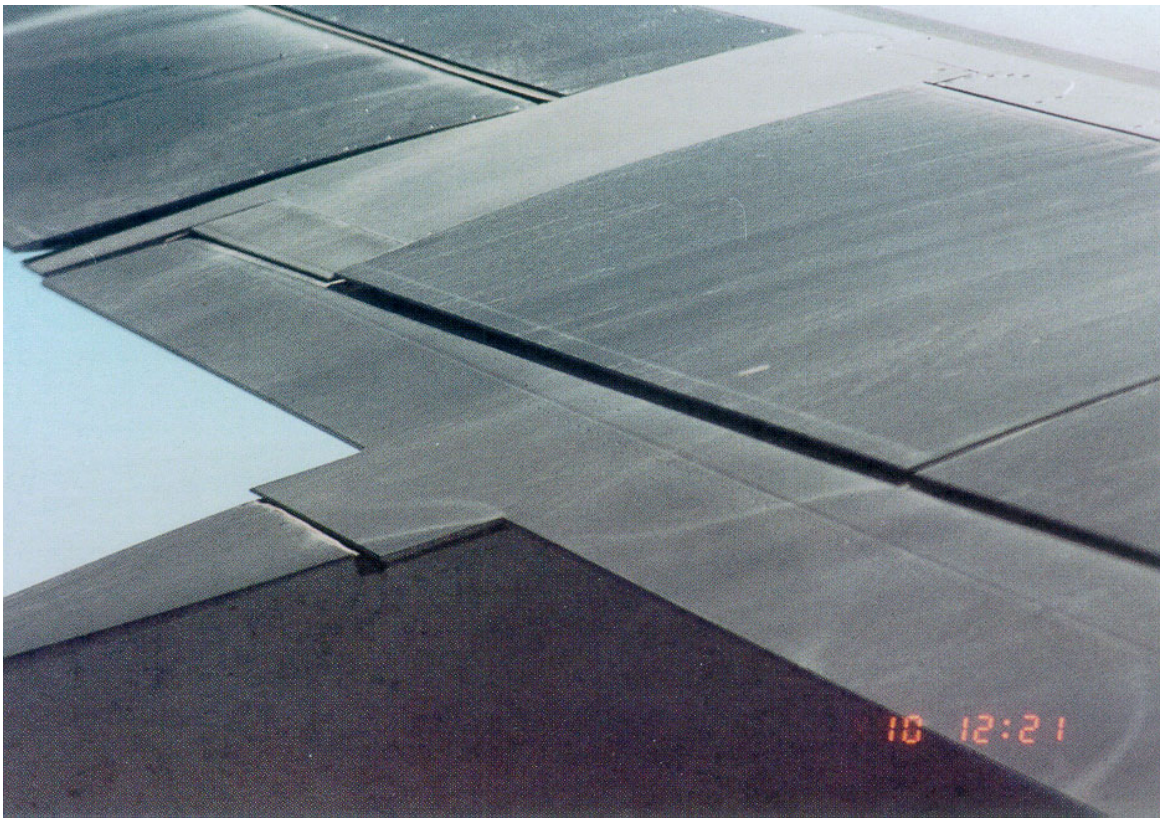
Control surface	Penalty in US gallons per year			**Penalty in US $ per year**			AMM reference	**Corrective action**		
	5mm height	10mm height	15mm height	5mm height	10mm height	**15mm height**		Men	Manhours	**Cost**
Slat 1	3,420	5,510	8,940	$ 2,050	$ 3,300	**$ 5,360**	27 84 61	2	5	**$ 250**
Slat 2, 3	5,100	8,230	13,340	$ 3,060	$ 4,940	**$ 8,000**		2	5	**$ 250**
Slat 4, 5	8,160	13,165	21,350	$ 4,900	$ 7,900	**$ 12,810**	27 84 62	2	5	**$ 250**
Flap	550	1,110	1,660	$ 330	$ 670	**$ 1,000**	27 51 00	2	7	**$ 350**
Spoiler	2,500	5,750	8,660	$ 1,500	$ 3,450	**$ 5,200**	27 64 00	1	2	**$ 100**
Aileron	520	1,010	1,530	$ 310	$ 610	**$ 920**	27 14 00	1	3	**$ 150**
Rudder	1,360	2,280	2,950	$ 820	$ 1,370	**$ 1,770**	27 24 00	2	3	**$ 150**
Misalign-ment at flap track fairing	640	1,280	1,600	$ 380	$ 770	**$ 960**	05 25 30	2	4	**$ 200**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

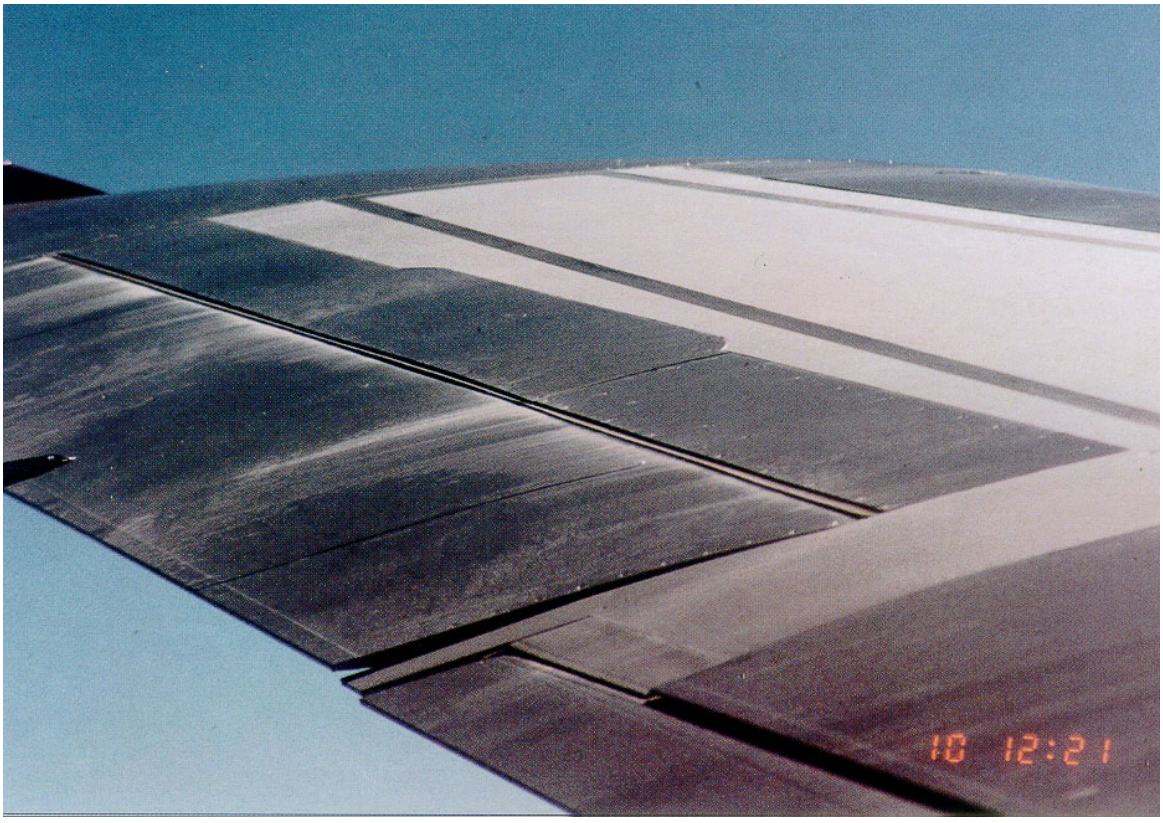
Misrigged slats



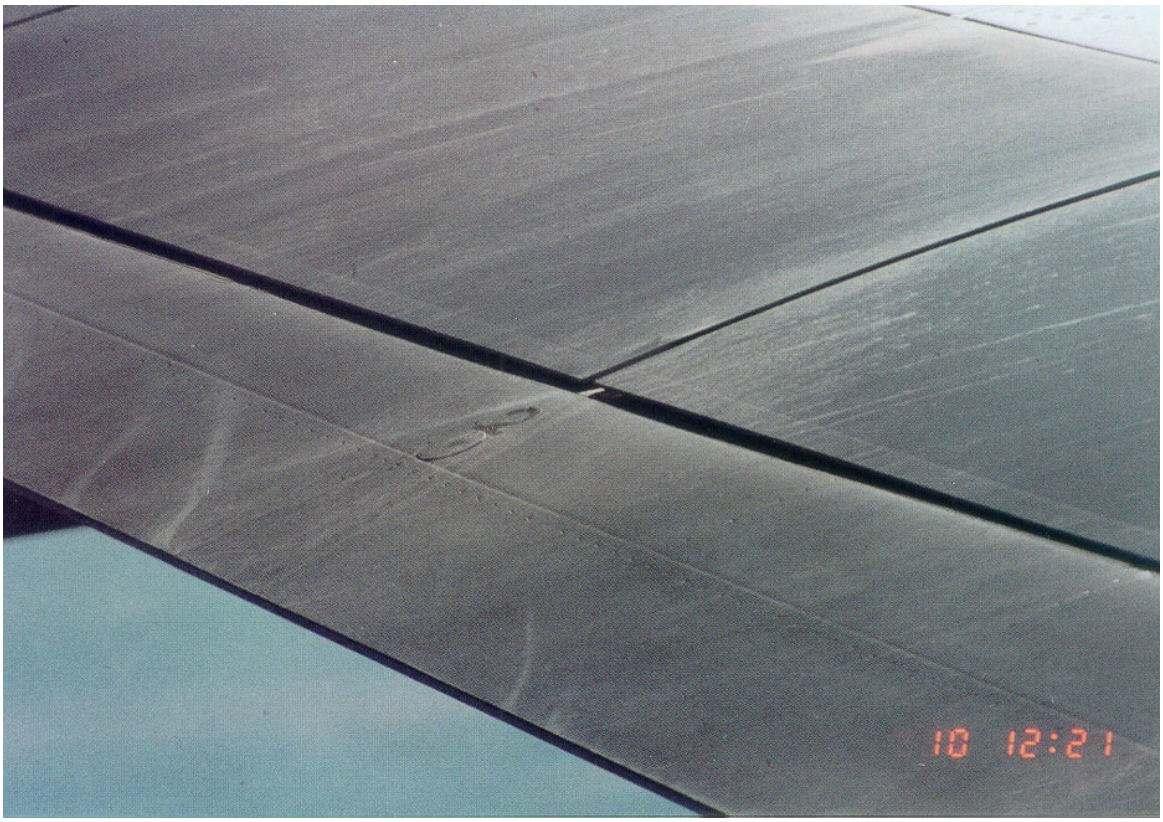
Misrigged spoilers

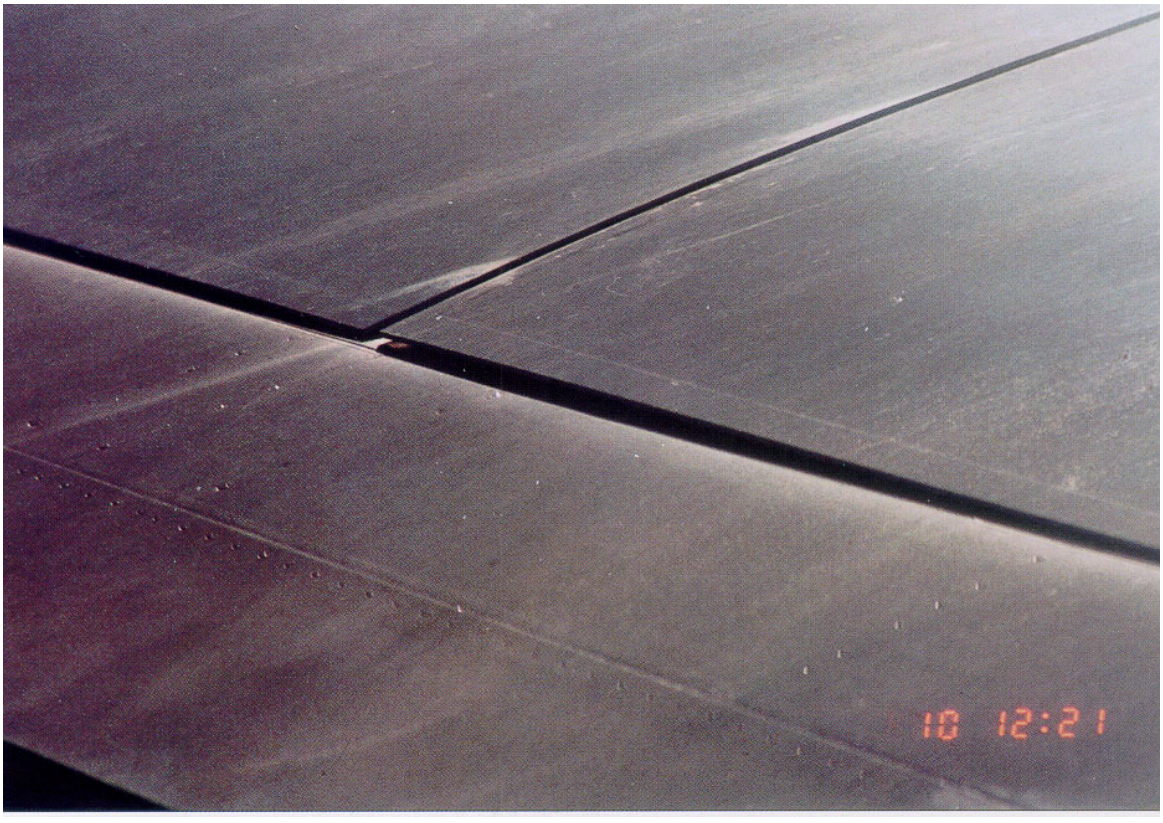


Misrigged spoiler and aileron

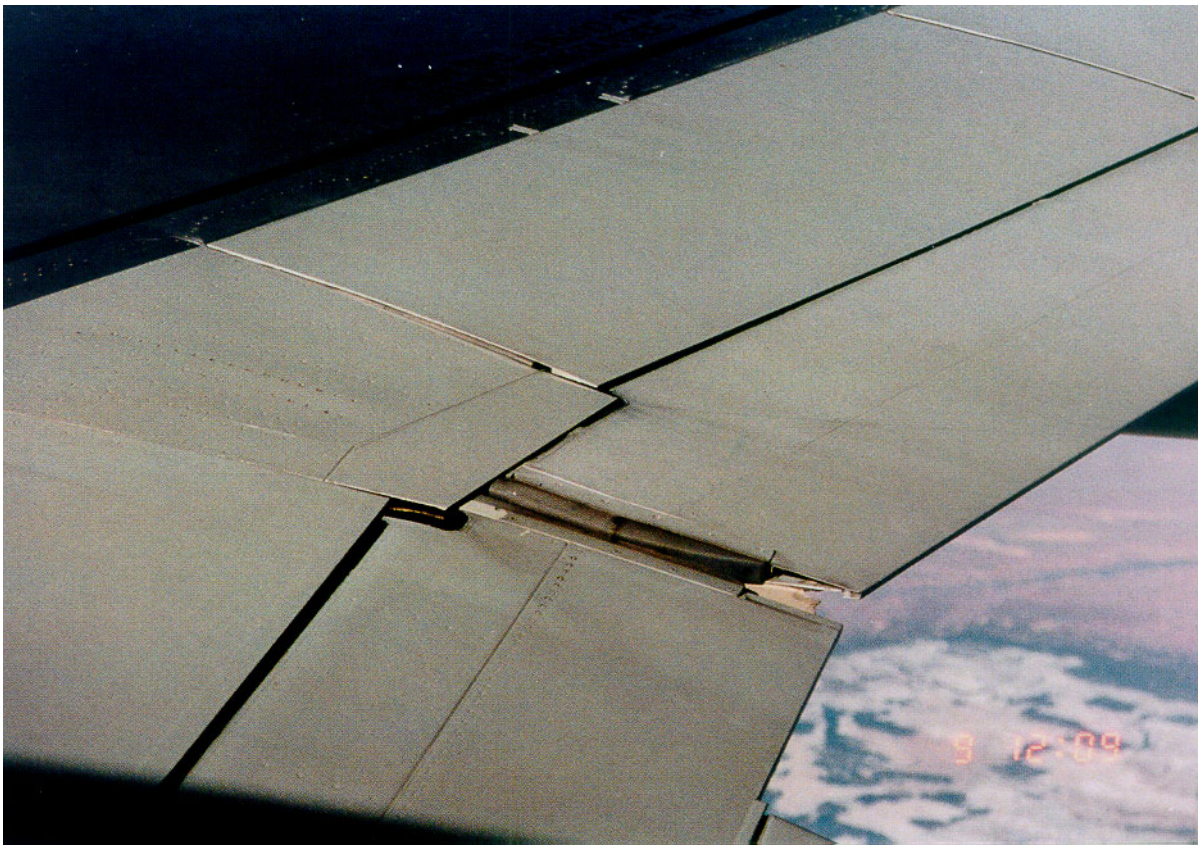


Misrigged spoilers

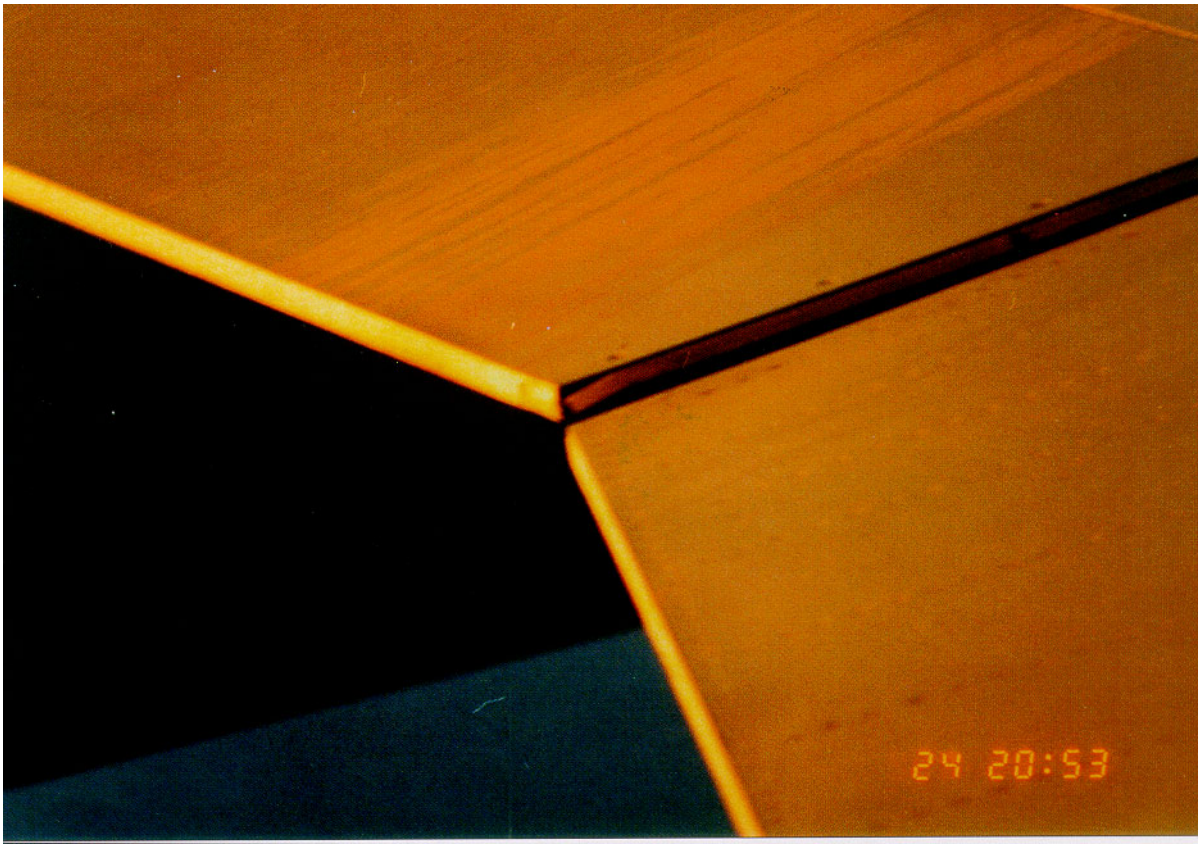




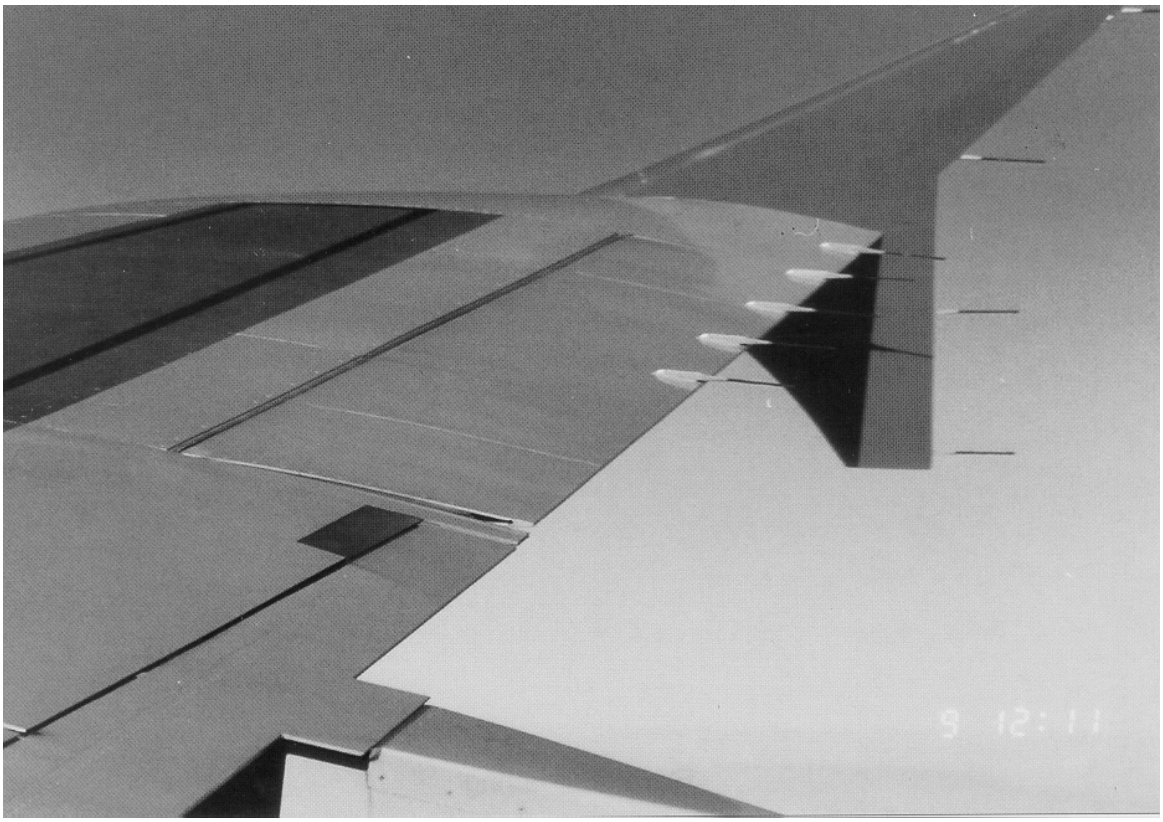
Flap

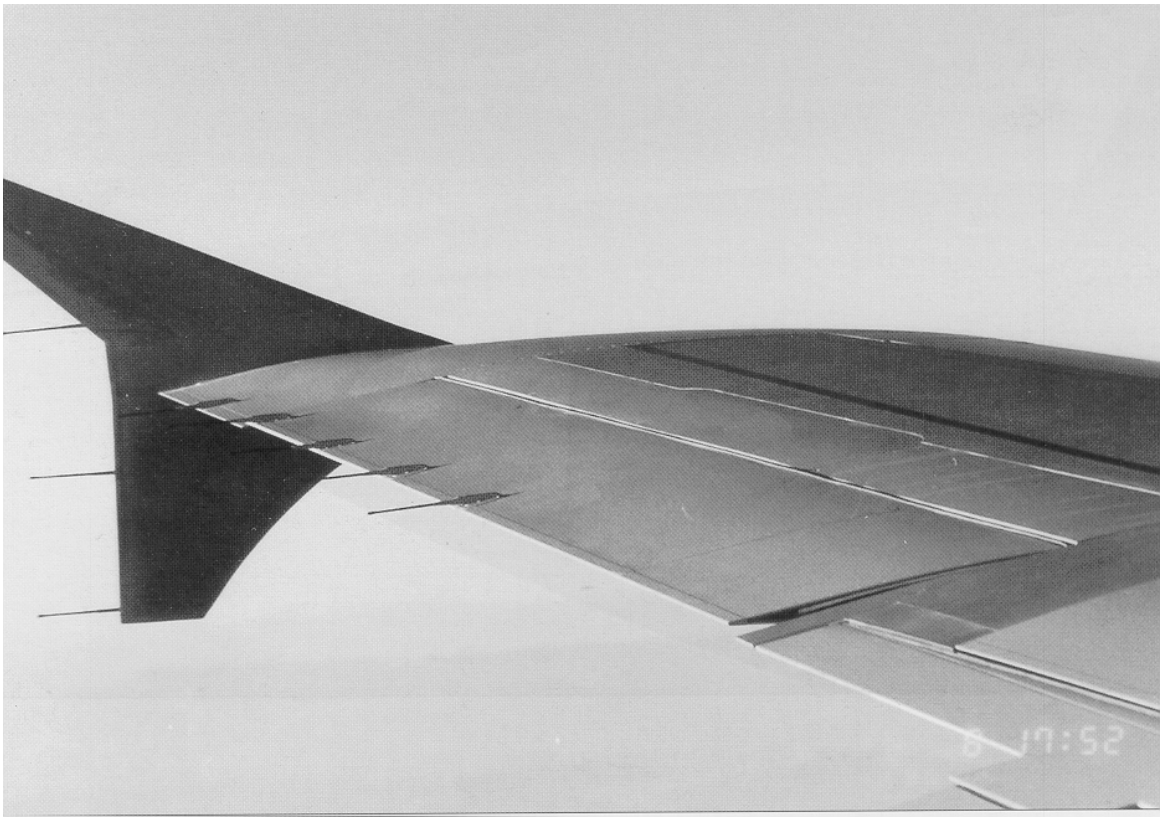


Aileron / flap

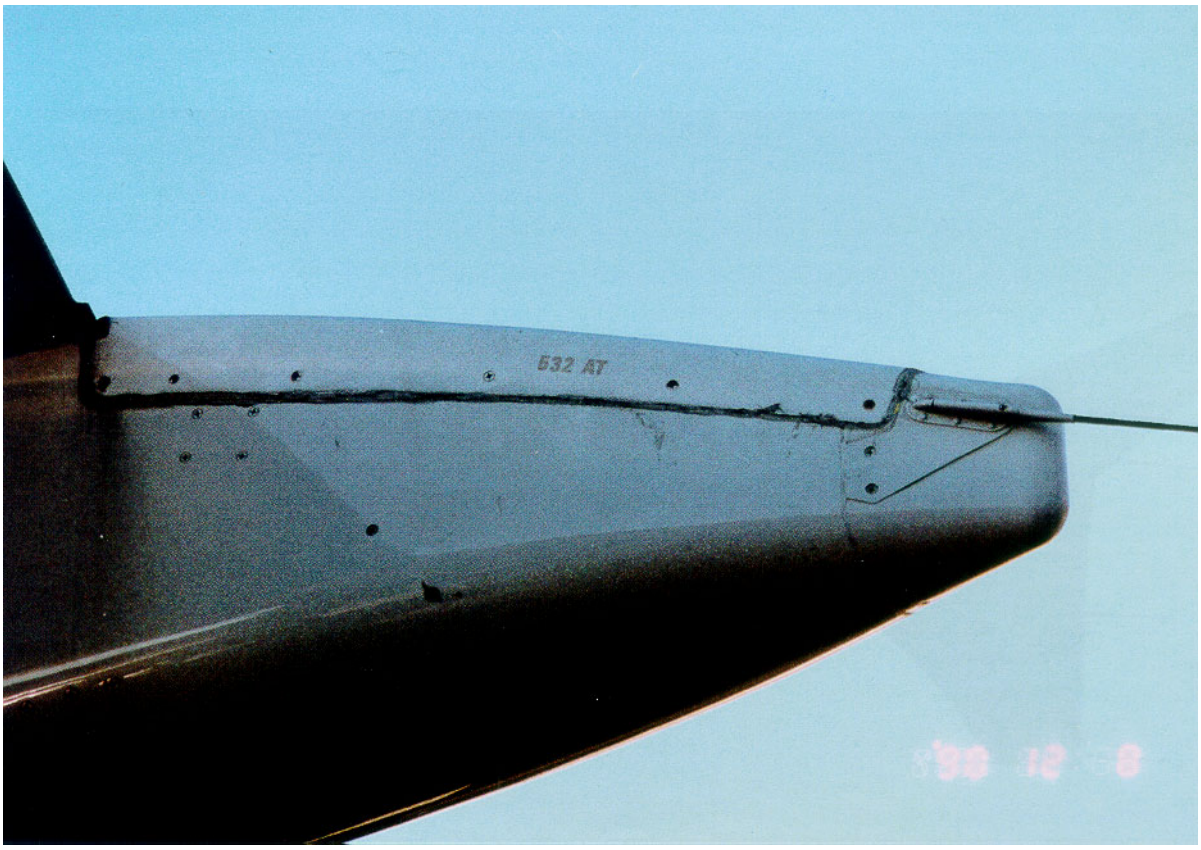


Ailerons

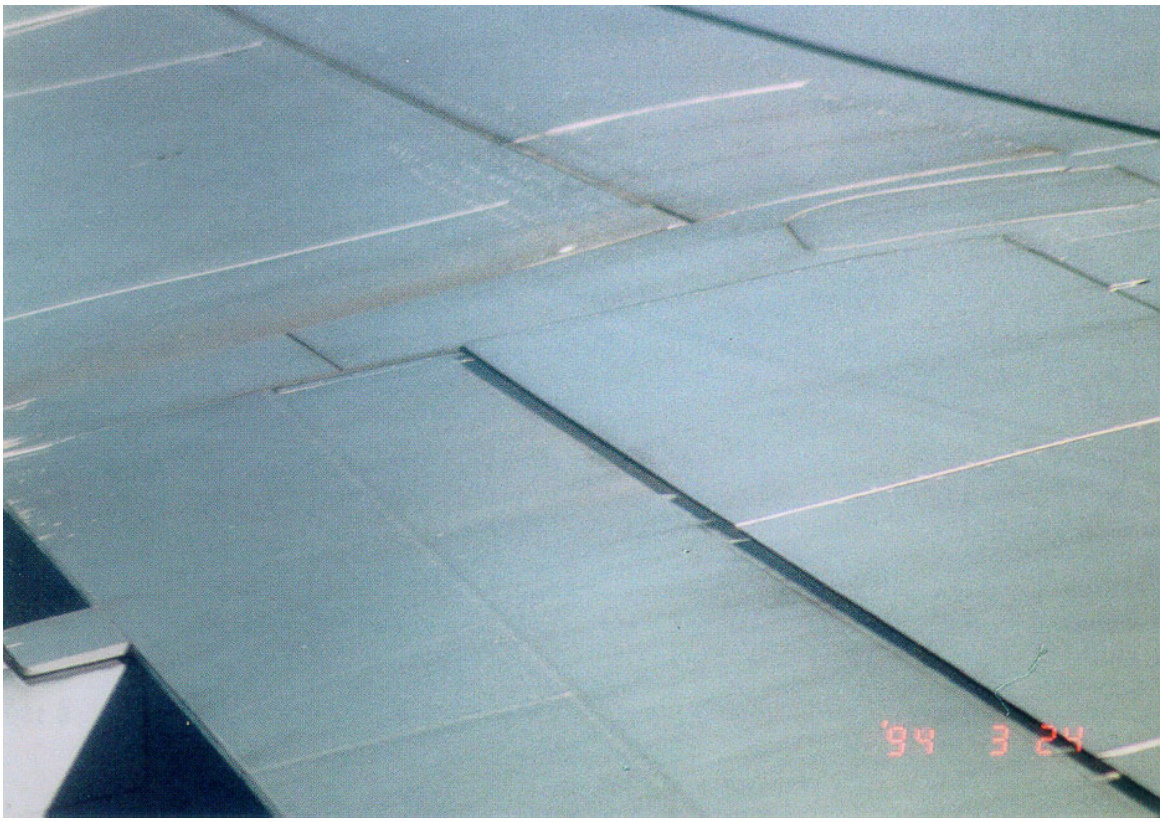


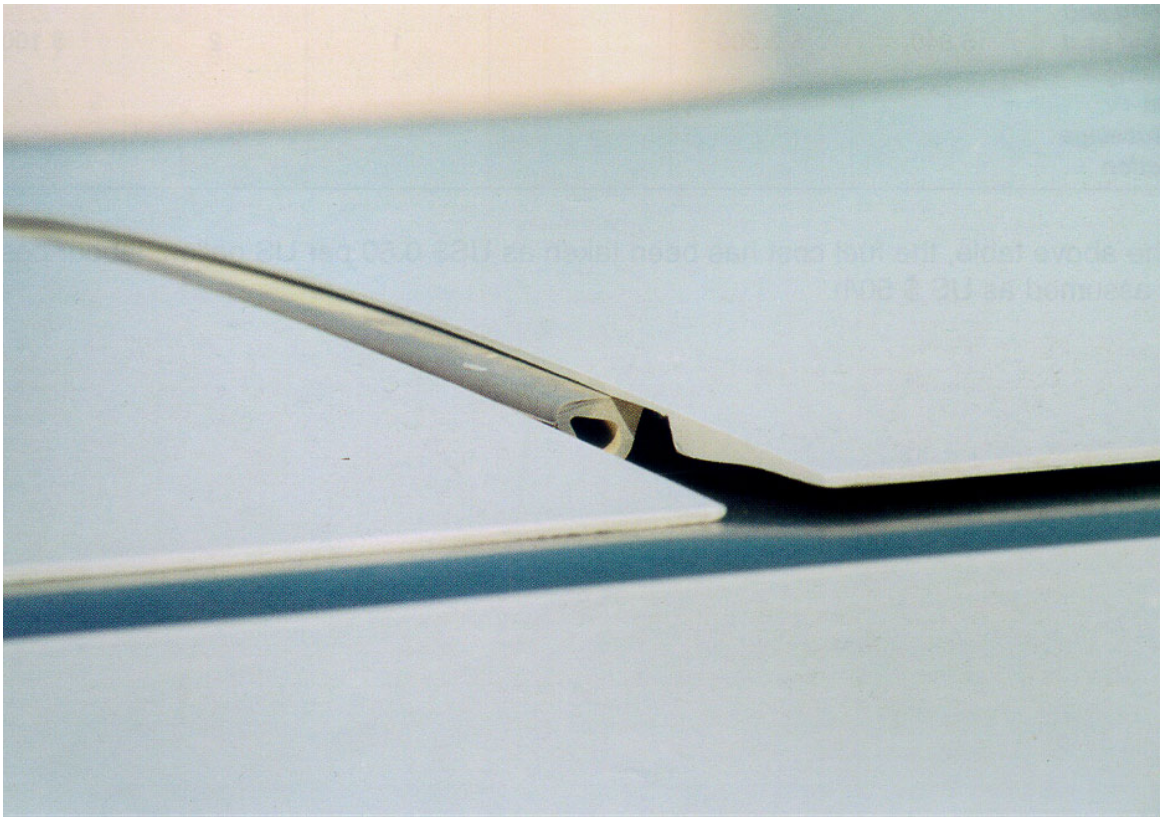


Flap track fairing



Misrigged spoilers





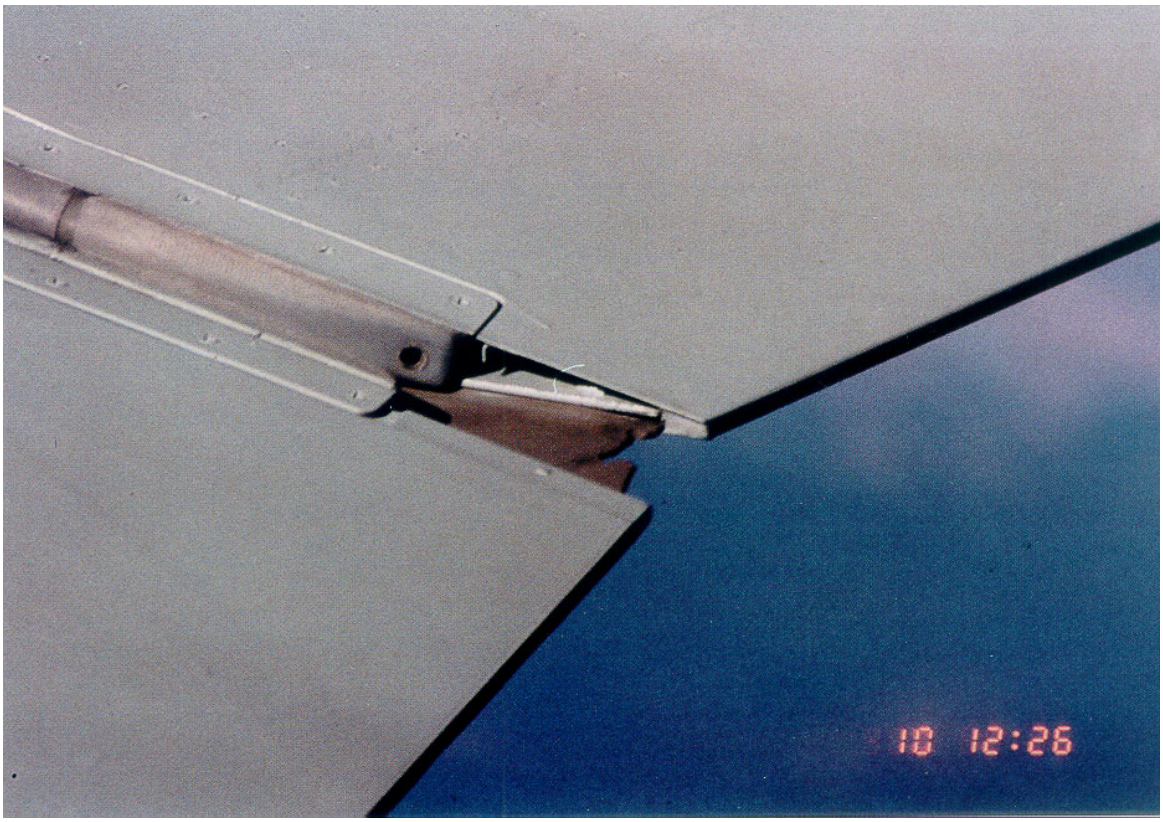
4.2 Absence of seals on movable sections

Values are given per meter of missing seal.

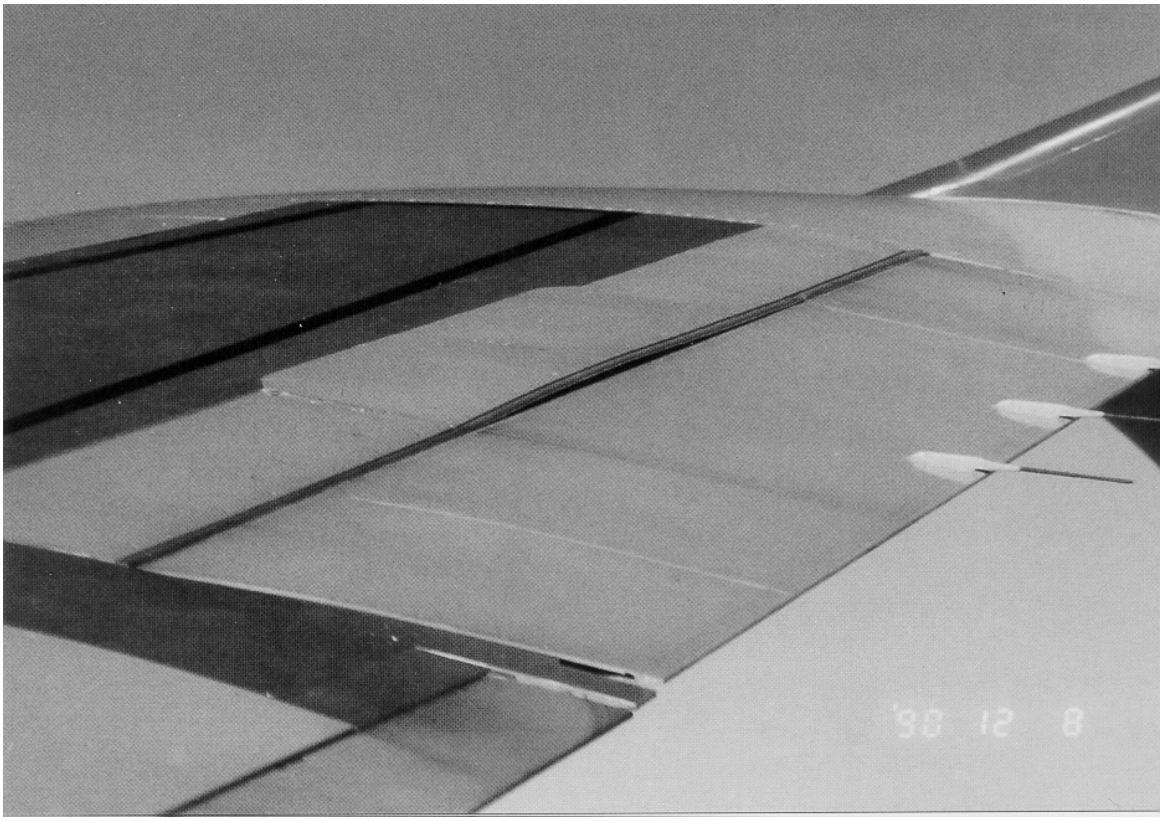
Control surface	Penalty in US gallons per year	**Penalty in US $ per year**	AMM reference	**Corrective action**		
				Men	Manhours	**Cost**
Slat 1 (spanwise seal)	1,630	**$ 980**	27 84 61	1	2	**$ 100**
Slat 2, 3 (spanwise seal)	2,428	**$ 1,450**	27 84 62	1	2	**$ 100**
Slat 4, 5 (spanwise seal)	3,880	**$ 2,330**	27 84 62	1	2	**$ 100**
Flap (chord-wise seal)	5,250	**$ 3,150**	27 54 61 27 54 62	1	2	**$ 100**
Wing surface-to-flap seal	2,120	**$ 1,270**	27 50 00	1	3	**$ 150**
Aileron (chord-wise seal)	5,250	**$ 3,150**	57 60 00	1	1	**$ 50**
Fairing and rubber seal missing from fin/fuselage junction	5,840	**$ 3,500**	27 21 00	1	2	**$ 100**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

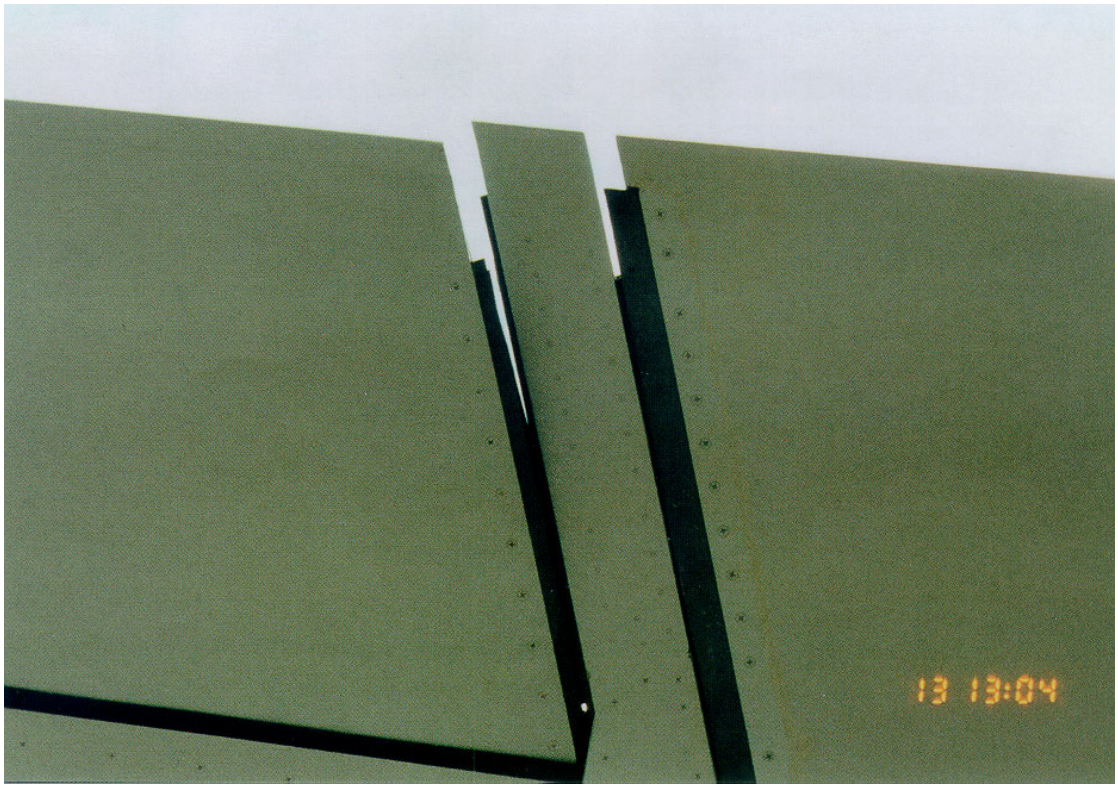
Damaged chordwise flap seal

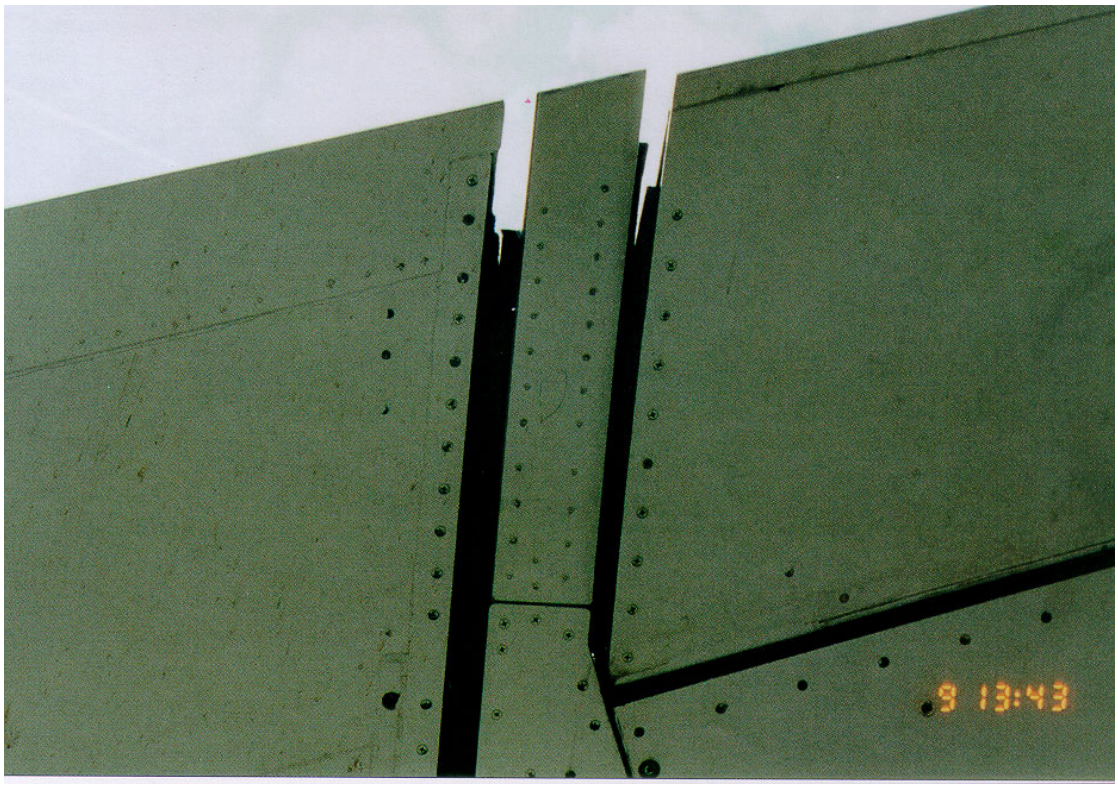


Damaged spanwise aileron seal



Aileron and flap seals





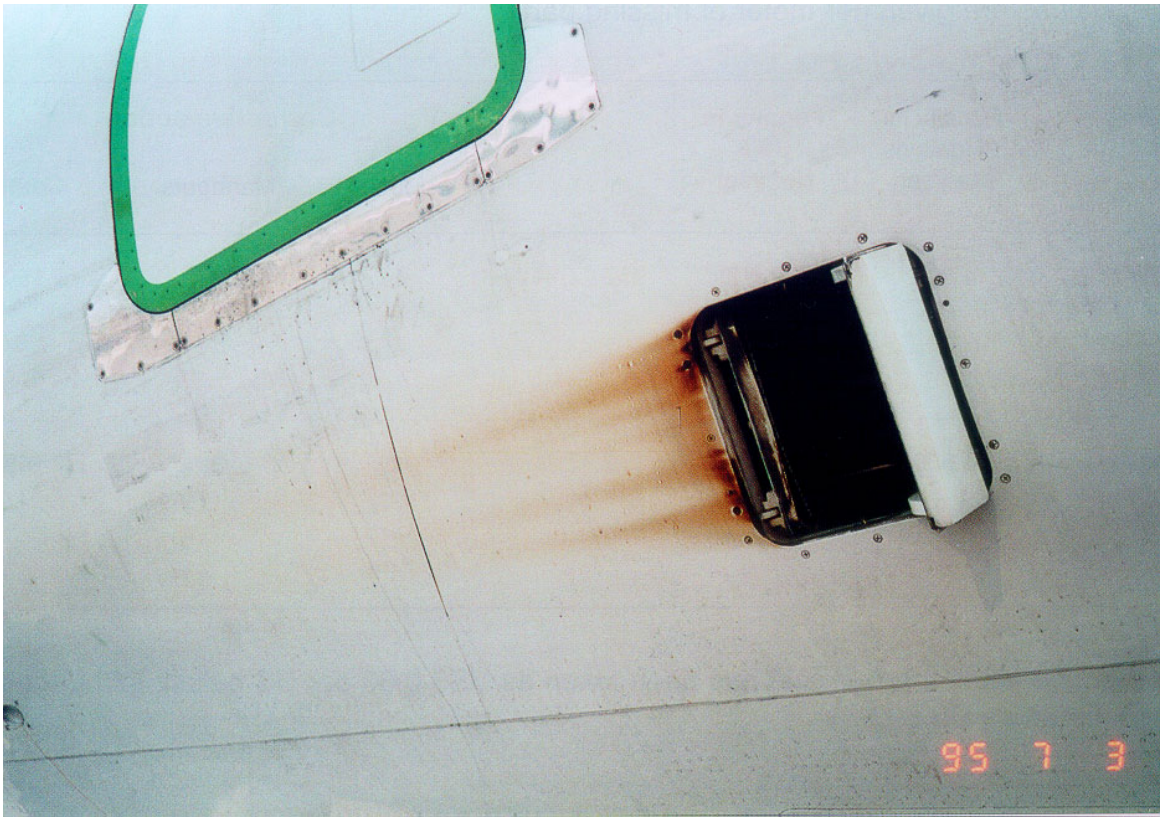
4.3 Missing parts

Values are given per meter of missing part.

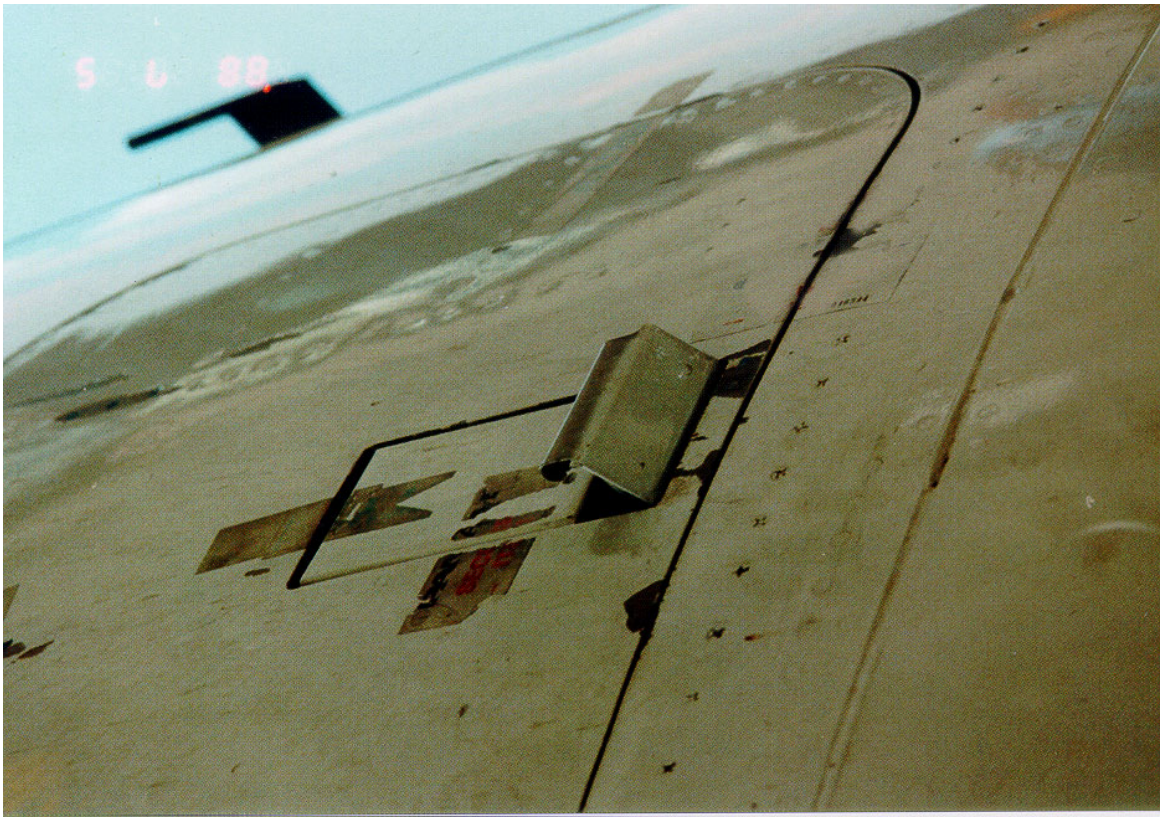
Missing part	Penalty in US gallons per year	**Penalty in US $ per year**	AMM reference	**Corrective action**		
				Men	Menhours	**Cost**
Access door in the fuselage Zone 1 area	4,680	**$ 2,800**	52 42 00	1	3	**$ 150**
Access door in the fuselage Zone 2 area	3,500	**$ 2,100**	52 42 00	1	3	**$ 150**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Exhaust door



Cargo door latch



4.4 Mismatched surfaces

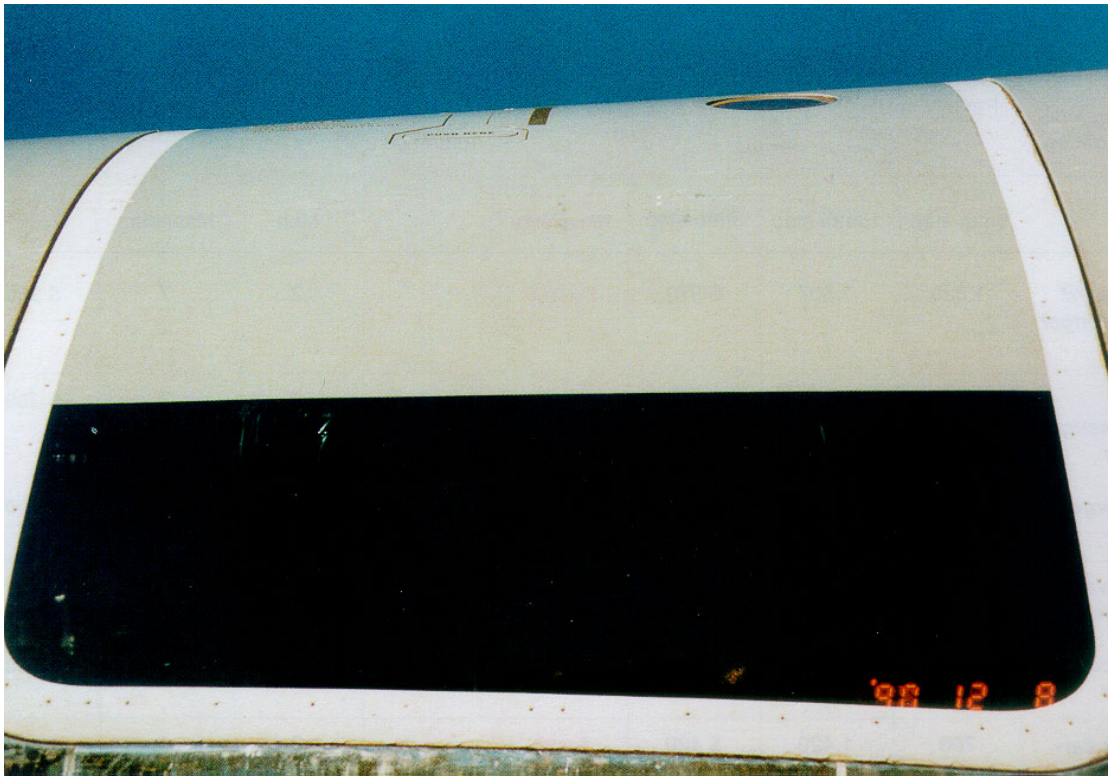
Values are given for a given per meter of mismatch.

Mismatched surface	Penalty in US gallons per year		**Penalty in US $ per year**		AMM reference	**Corrective action**		
	5mm step	10mm step	5mm step	10mm step		Men	Manhours	**Cost**
Forward passenger door	1,620	3,507	$ 970	**$ 2,100**	52 11 00	2	7	**$ 350**
Aft passenger door	1,150	2,450	$ 690	**$ 1,470**	52 13 00	2	7	**$ 350**
Emergency exit	770	1,680	$ 460	**$ 1,010**	52 21 11	2	6	**$ 300**
Forward cargo door	1,950	3,890	$ 1,170	**$ 2,330**	52 31 11	2	12	**$ 600**
Aft cargo door	1,530	3,560	$ 920	**$ 2,140**	52 31 11	2	12	**$ 600**
Bulk cargo door	700	1,420	$ 420	**$ 853**	52 33 11	2	4	**$ 200**
Main landing gear door	800	1,860	$ 480	**$ 1,110**	32 12 11	2	7	**$ 350**
Nose landing gear door	1,000	2,360	$ 600	**$ 1,420**	32 22 11	2	5	**$ 250**
Access door in Zone 1 area	390	1,030	$ 230	**$ 620**	no specific procedure			
Radome misfit (maximum allowed)	490		**$ 300**		53 15 11	2	6	**$ 250**

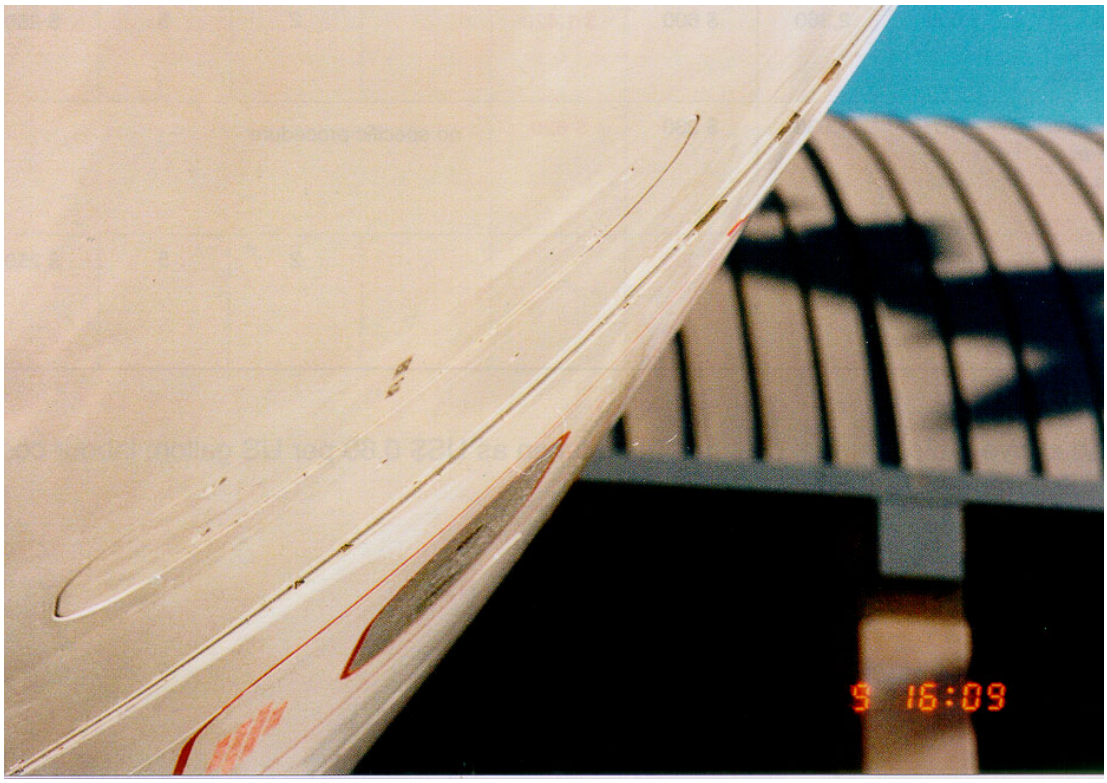
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Passenger door

perfectly matched

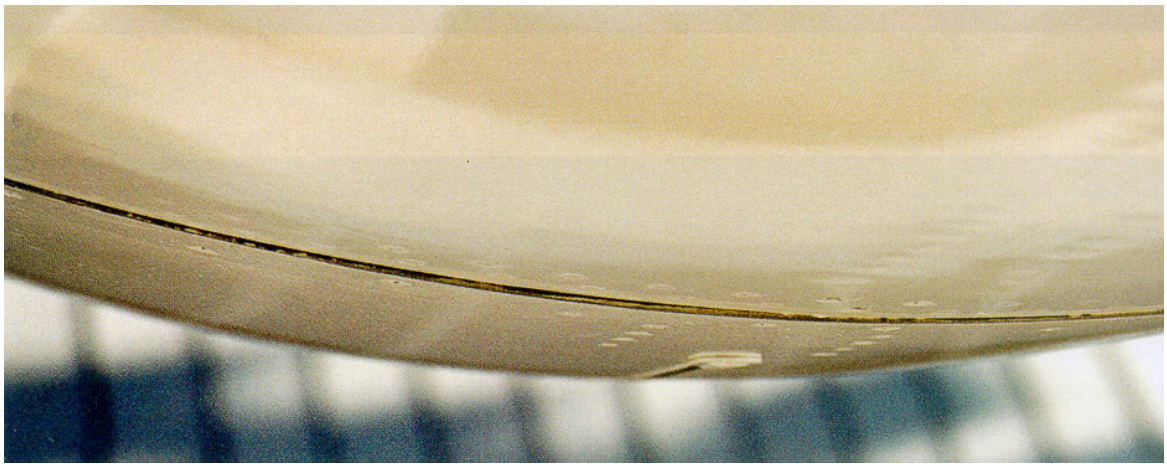


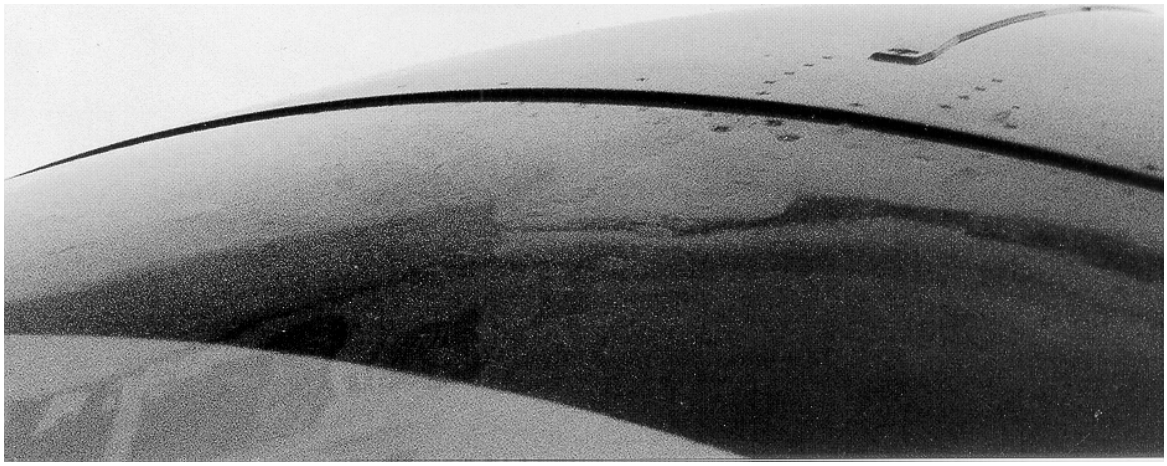
Mismatched cargo door



Mismatched access doors

Radome misfit





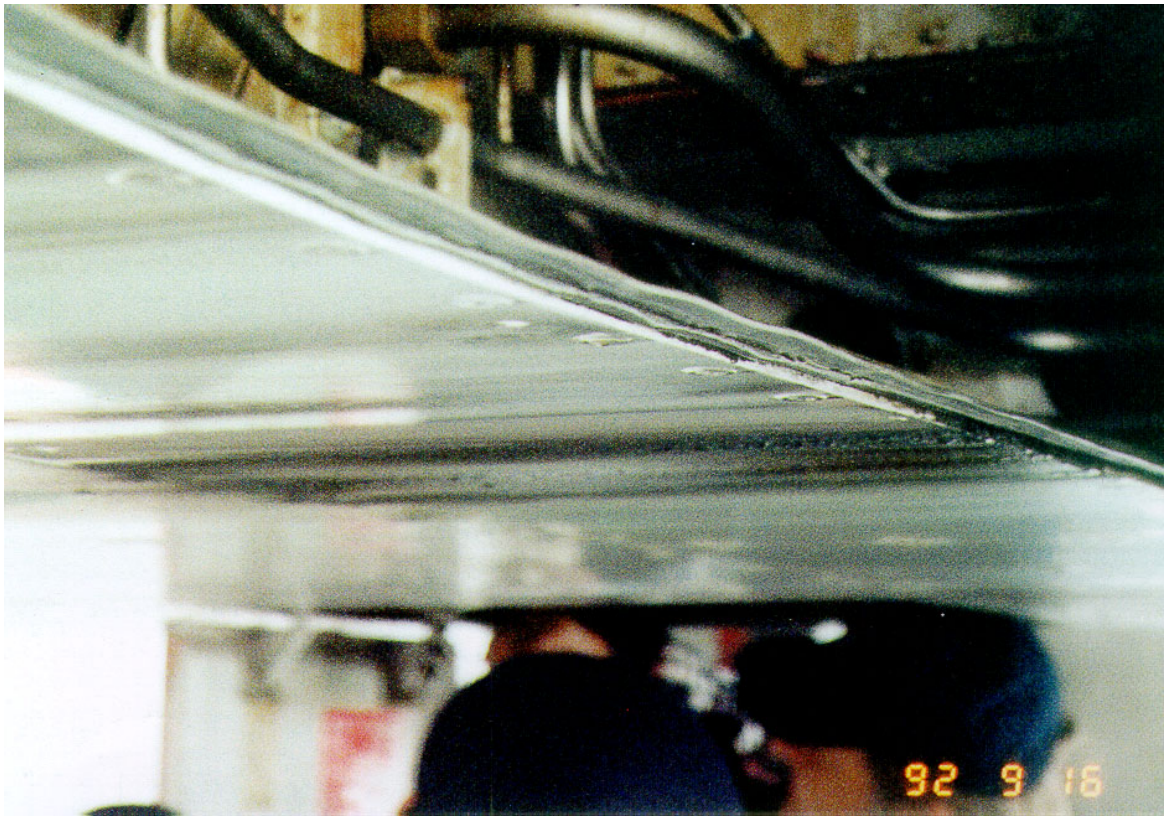
4.5 Door seal leakage

Values are given for a 5cm damaged door seal section.

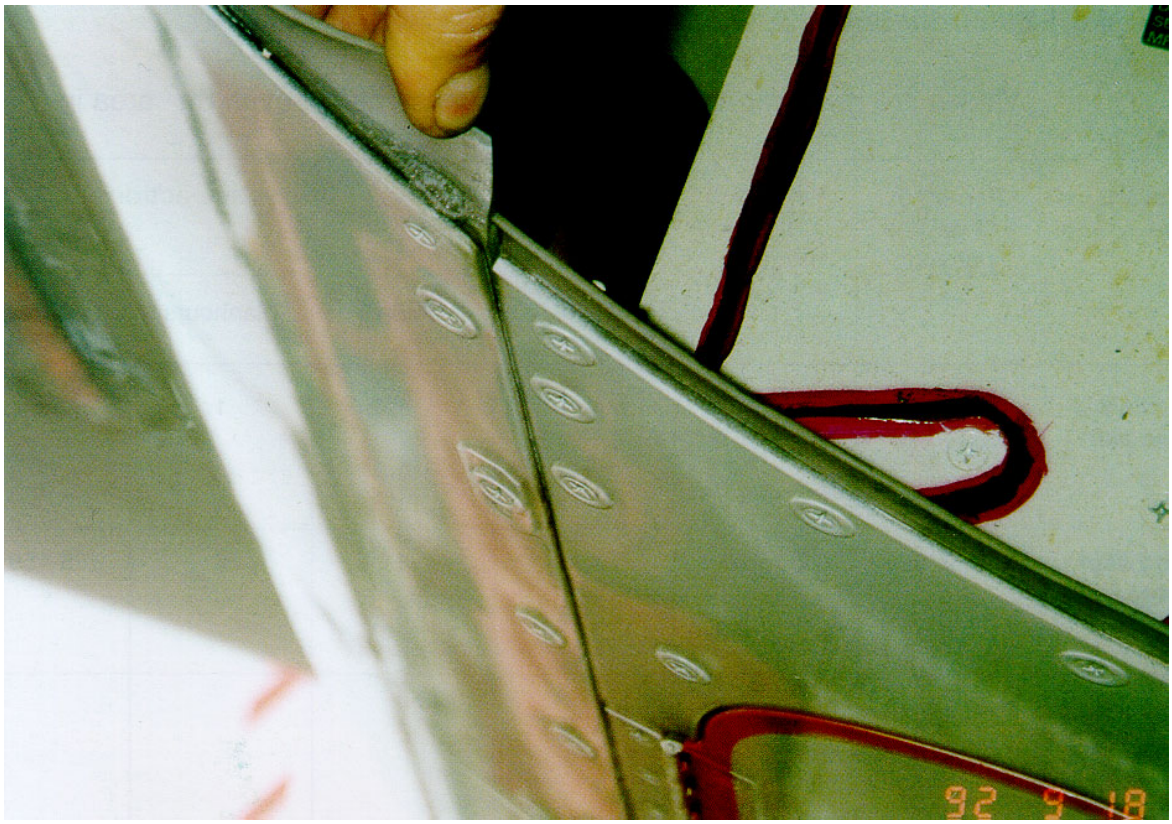
Item	Penalty in US gallons per year		Penalty in US $ per year		AMM reference	Corrective action		
	Sides	Top or bottom	Sides	Top or bottom		Men	Manhours	Cost
Forward passenger door	340	170	$ 200	$ 100	52 11 18	2	7	$ 350
Aft passenger door	200	100	$ 120	$ 60	52 13 18	2	7	$ 350
Emergency exit	110	60	$ 70	$ 40	52 22 00	2	6	$ 300
Forward cargo door	270	140	$ 160	$ 80	52 31 18	2	10	$ 500
Aft cargo door	220	120	$ 130	$ 70	52 31 18	2	10	$ 500

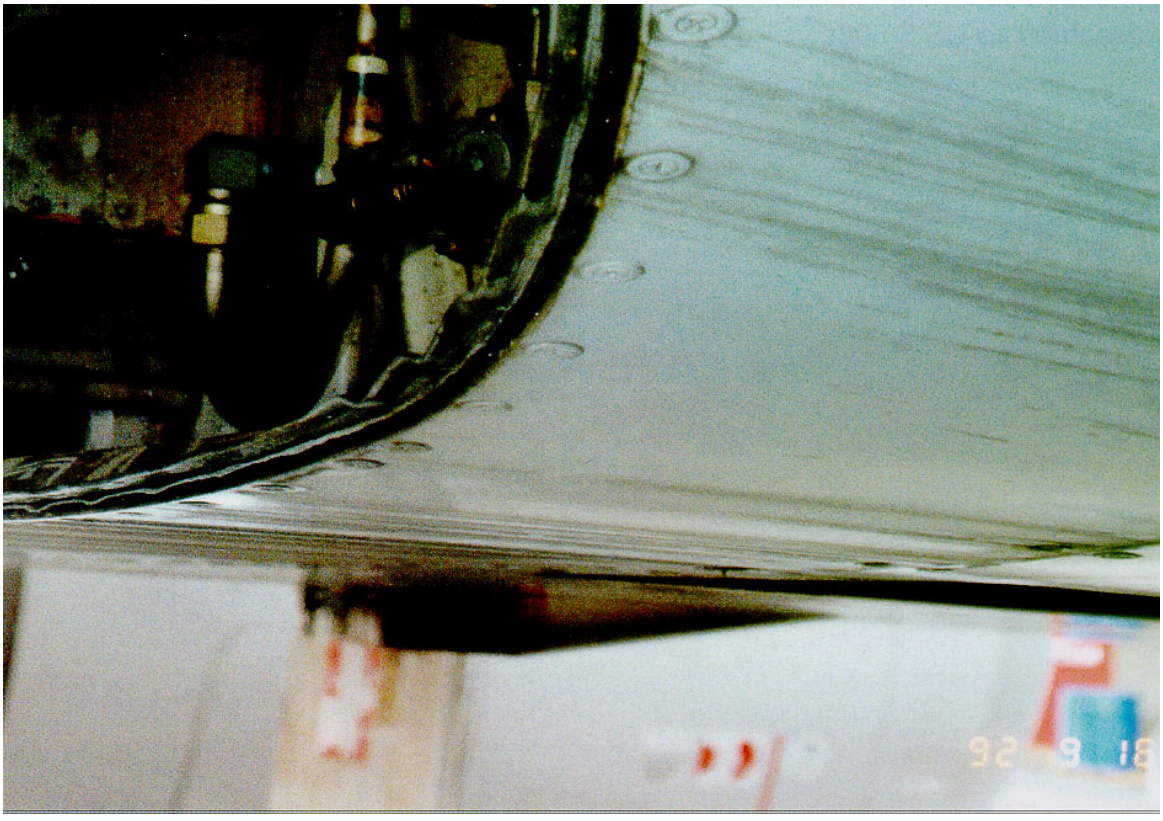
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Damaged seal



Damaged seal





4.6 Surface deterioration

4.6.1 Skin roughness

Values are given for a 0.3mm skin roughness height over 1m^2 area in Zone 1.

Affected area	Penalty in US gallons per year	**Penalty in US $ per year**	Maintenance reference	**Corrective action**		
			SRM 51 10 00	Men	Manhours	**Cost**
Leading edge slat	4,900	**$ 2,940**	External cleaning AMM 51 78 00	1	1	**$ 50**
Wing skin – upper	2,970	**$ 1,780**	Polishing AMM 51 21 00	1	3	**$ 150**
Wing skin – lower	1,460	**$ 880**				
Tail	940	**$ 560**				
Fuselage	600	**$ 360**				

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

4.6.2 Skin dents

Values are given for a single dent or blister in specific areas.

Affected area	Surface dama-ged	Penalty in US gallons per year		**Penalty in US $ per year**		Maint. reference	**Corrective action**		
		5mm	10mm	5 mm	**10 mm**	SRM 51 73 00 AMM 51 73 11	Men	Manhours	**Cost**
Leading edge slat	20 cm^2	35	35	$ 21	**$ 21**	27 80 00	2	24	**$ 1,200**
	80 cm^2	150	170	$ 90	**$ 100**		2	60	**$ 3,000**
Wing (Zone 1)	20 cm^2	21	21	$ 13	**$ 13**	57 00 00	2	24	**$ 1,200**
	80 cm^2	90	101	$ 54	**$ 61**		2	60	**$ 3,000**
Tail (Zone 1)	20 cm^2	7	19	$ 4	**$ 11**	55 00 00	2	24	**$ 1,200**
	80 cm^2	15	30	$ 9	**$ 18**		2	40	**$ 2,000**
Fuselage (Zone 2)	20 cm^2	2	5	$ 1	**$ 3**	53 00 00	2	16	**$ 800**
	80 cm^2	5	9	$ 3	**$ 5**		2	40	**$ 2,000**
Scuff plate at forward pax door		110	270	$ 70	**$ 160**	AMM 53 15 15	1	1	**$ 50**
Scuff plate at forward cargo door		100	260	$ 60	**$ 160**	AMM 53 45 15	1	1	**$ 50**
Scuff plate at bulk door		60	150	$ 40	**$ 90**	AMM 53 45 15	1	1	**$ 50**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

For the fuselage Zone 1 areas, multiply the above values by 1.4

For the wing Zone 2 areas, divide the above values by 1.23

For the tail Zone 2 areas, divide the above values by 1.3

Dented door

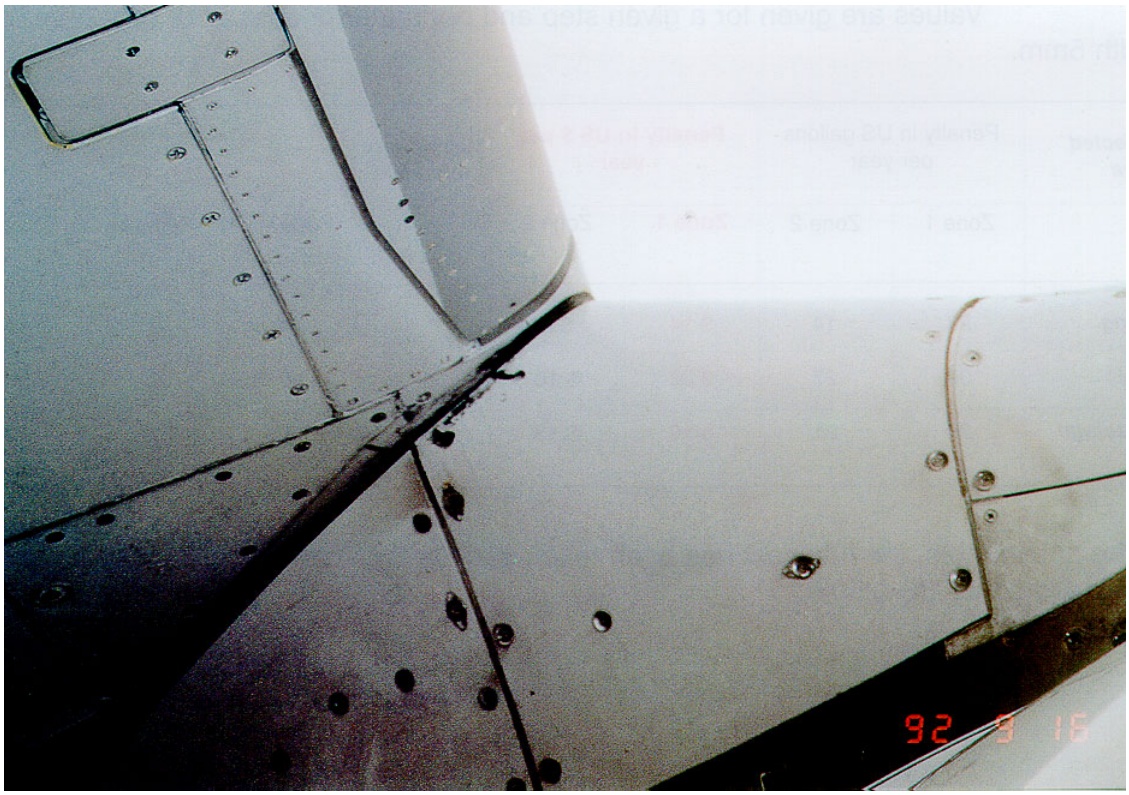
4.6.3 Unfilled butt joint gaps

Values are given for a given step and per meter of sealant of gap 2mm and width 5mm.

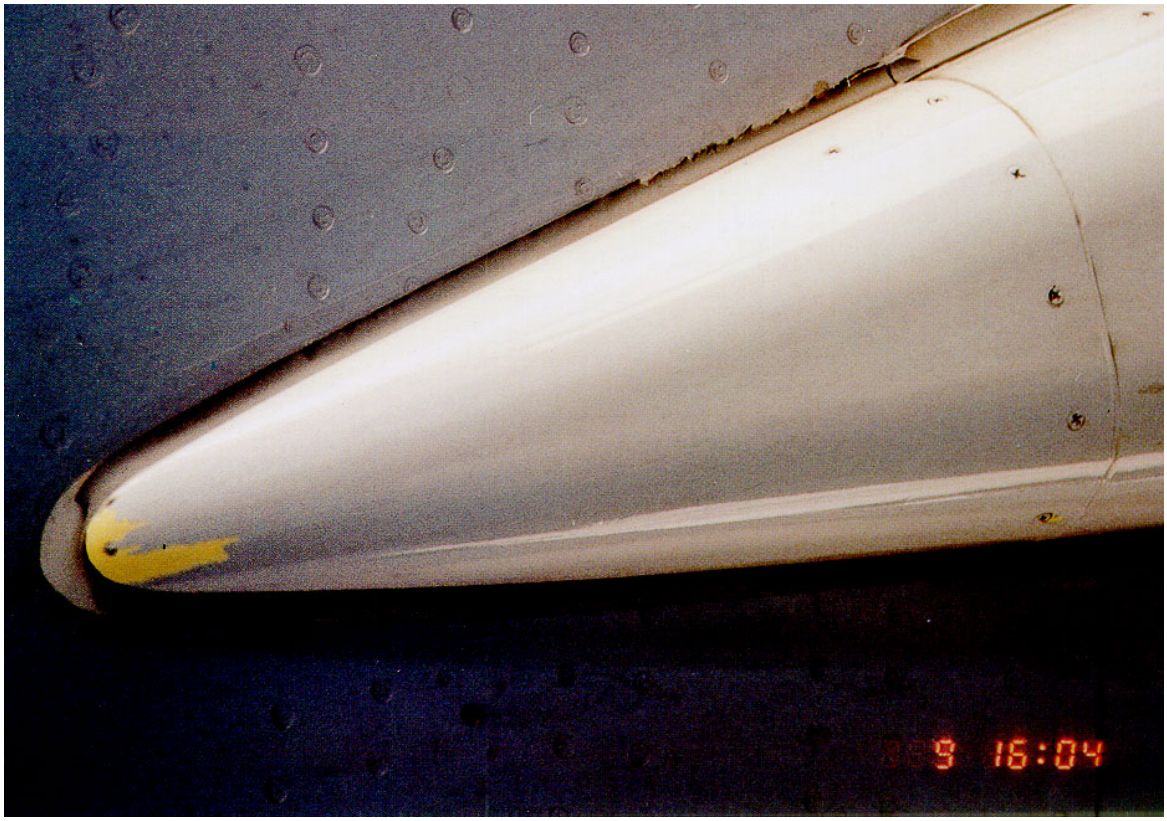
Affected area	Penalty in US gallons per year		**Penalty in US $ per year**		Maint. reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Wing	23	14	**$ 14**	$ 8		1	2	**$ 100**
Tail	36	27	**$ 22**	$ 16		1	2	**$ 100**
Fuselage	27	21	**$ 16**	$ 13	SRM 51 76 11	1	2	**$ 100**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

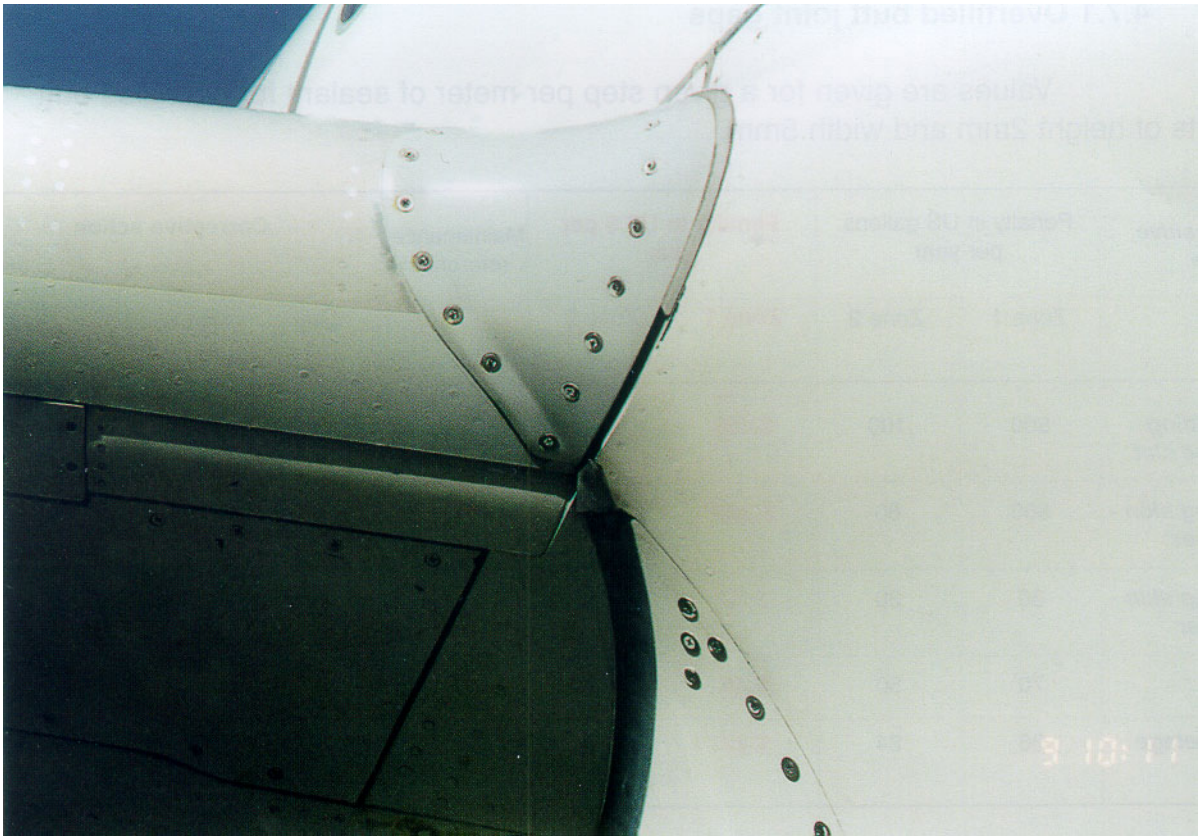
Seal missing



Seal missing



Seal missing



4.7 Consequences of hasty repairs

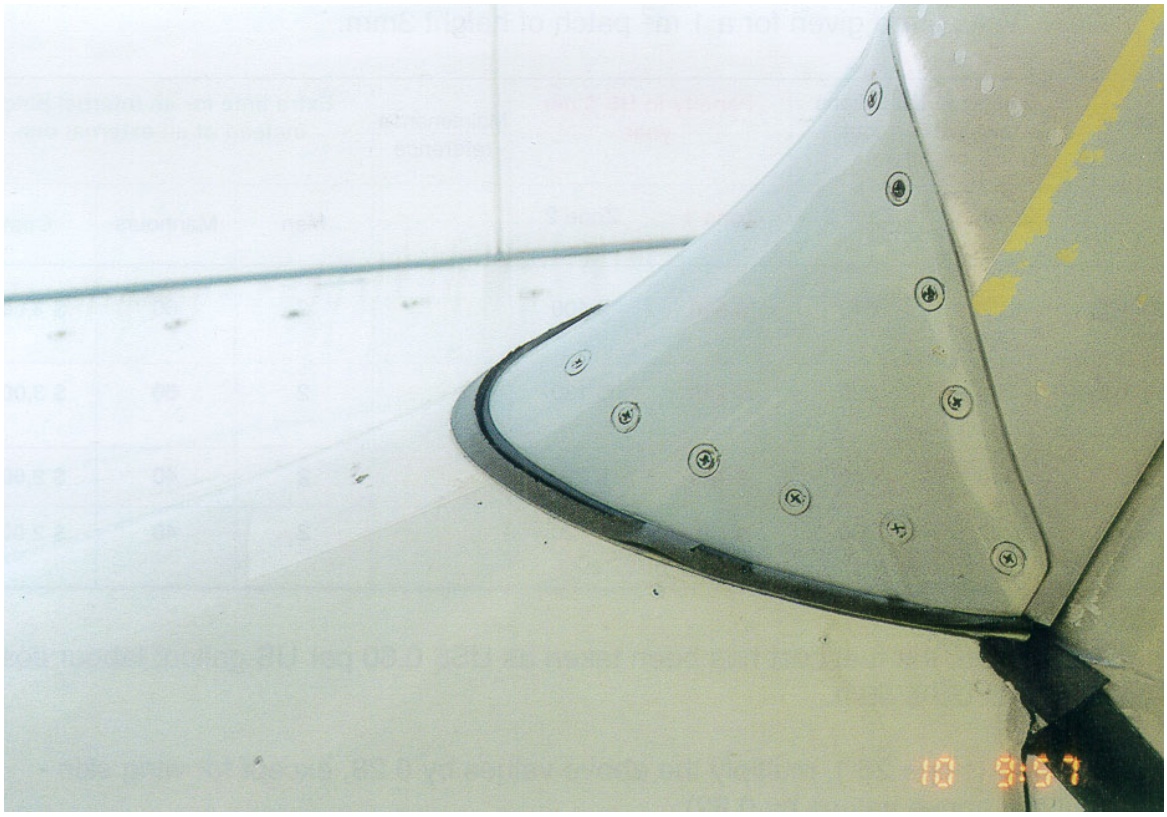
4.7.1 Overfilled butt joint gaps

Values are given for a given step per meter of sealant for overfilled butt joints of height 2mm and width 5mm.

Sensitive area	Penalty in US gallons per year		**Penalty in US $ per year**		Maint. reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Leading edge slat	800	100	**$ 480**	$ 60		1	2	**$ 100**
Wing skin - upper	500	60	**$ 300**	$ 40		1	2	**$ 100**
Wing skin - lower	30	20	**$ 20**	$ 10		1	2	**$ 100**
Tail	70	50	**$ 40**	$ 30		1	2	**$ 100**
Fuselage	36	24	**$ 22**	$ 14	SRM 51 76 11	1	2	**$ 100**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Seal misfit



Seal misfit

4.7.2 External patches

Values are given for a 1 m^2 patch of height 3 mm.

Sensitive area	Penalty in US gallons per year without chamber		**Penalty in US $ per year**		Maint. reference	**Extra time for an Internal patch instead of an external one**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Wing skin - upper	1,070	670	**$ 640**	$ 400	57 00 00	2	60	**$ 3,000**
Wing skin - lower	230	220	**$ 140**	$ 130	57 00 00	2	60	**$ 3,000**
Tail	540	360	**$ 320**	$ 220	55 00 00	2	40	**$ 2,000**
Fuselage	280	200	**$ 170**	$ 120	53 00 00	2	40	**$ 2,000**

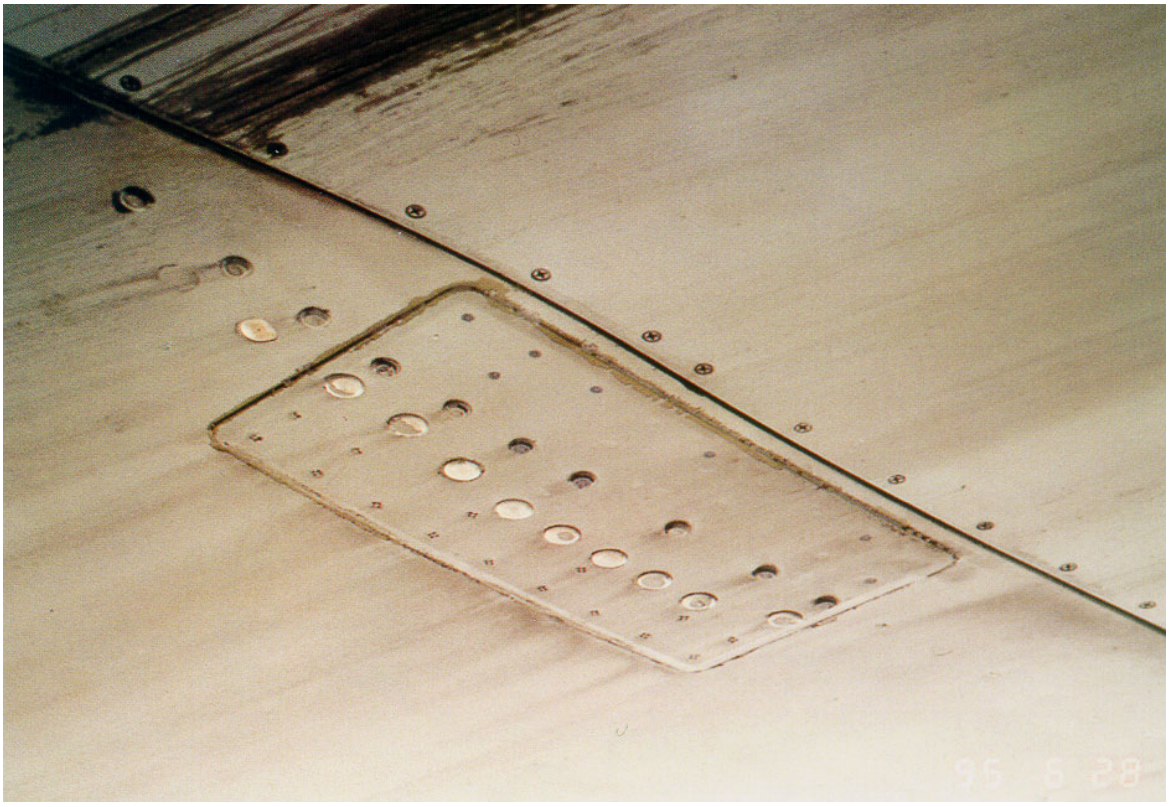
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

With a chamfer (slope 26°), multiply the above values by 0.28, except for wing skin – upper (multiply the above values by 0.82).

External patches

External patches

on the belly fairing



4.7.3 Paint peeling

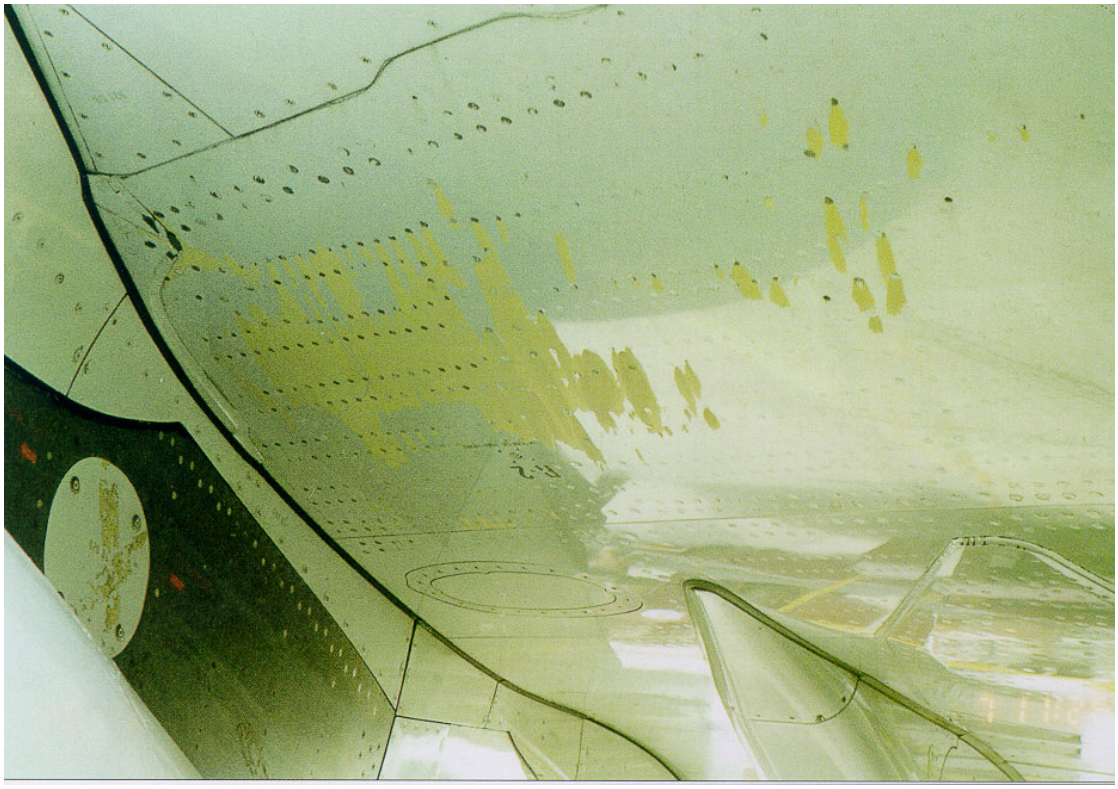
Values are given for a high-density paint peeling over a 1 m^2 area.

Sensitive area	Penalty in US gallons per year		**Penalty in US $ per year**		Maintenance reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Leading edge slat	2,830	1,740	**$ 1,700**	$ 1,040	Repair of paint damage	1	8	**$ 400**
Wing skin - upper	1,770	1,090	**$ 1,060**	$ 650	AMM 51 75 12 SRM 51 75 12	1	8	**$ 400**
Wing skin - lower	710	710	**$ 430**	$ 430		1	8	**$ 400**
Tail	540	400	**$ 330**	$ 240		1	8	**$ 400**
Fuselage	350	200	**$ 210**	$ 120		1	8	**$ 400**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

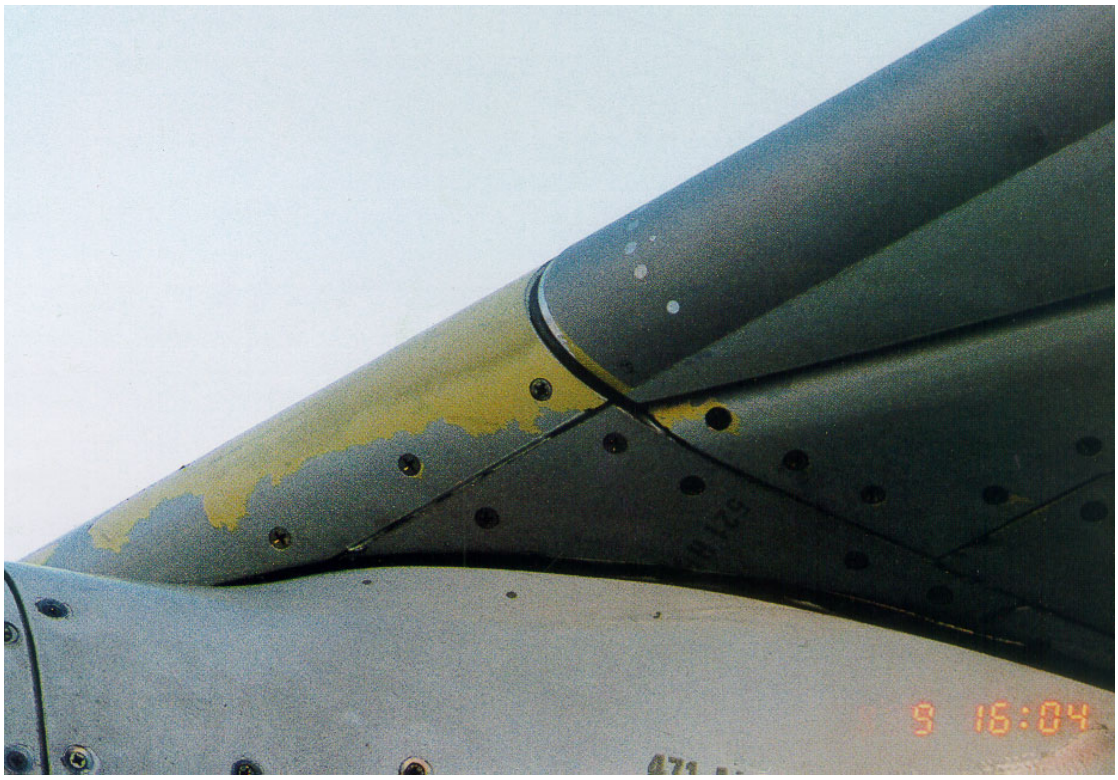
Paint peeling on the
belly fairing

Paint peeling on the
lower wing

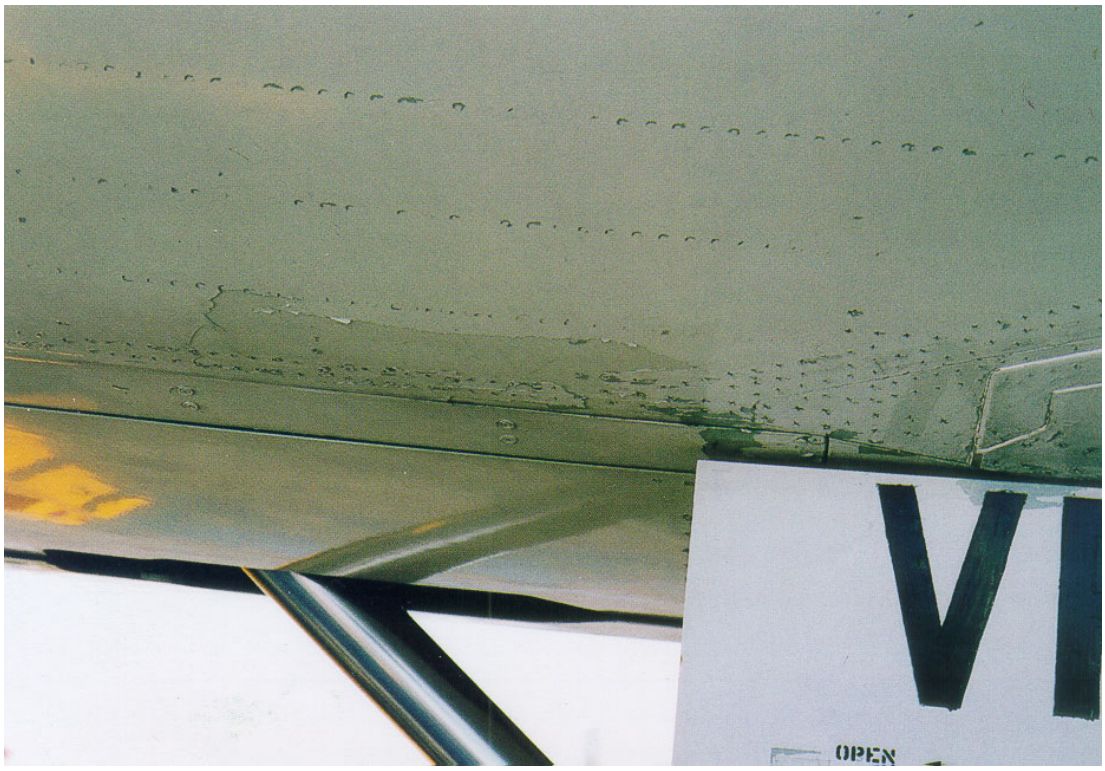


Paint peeling on the upper-
wing

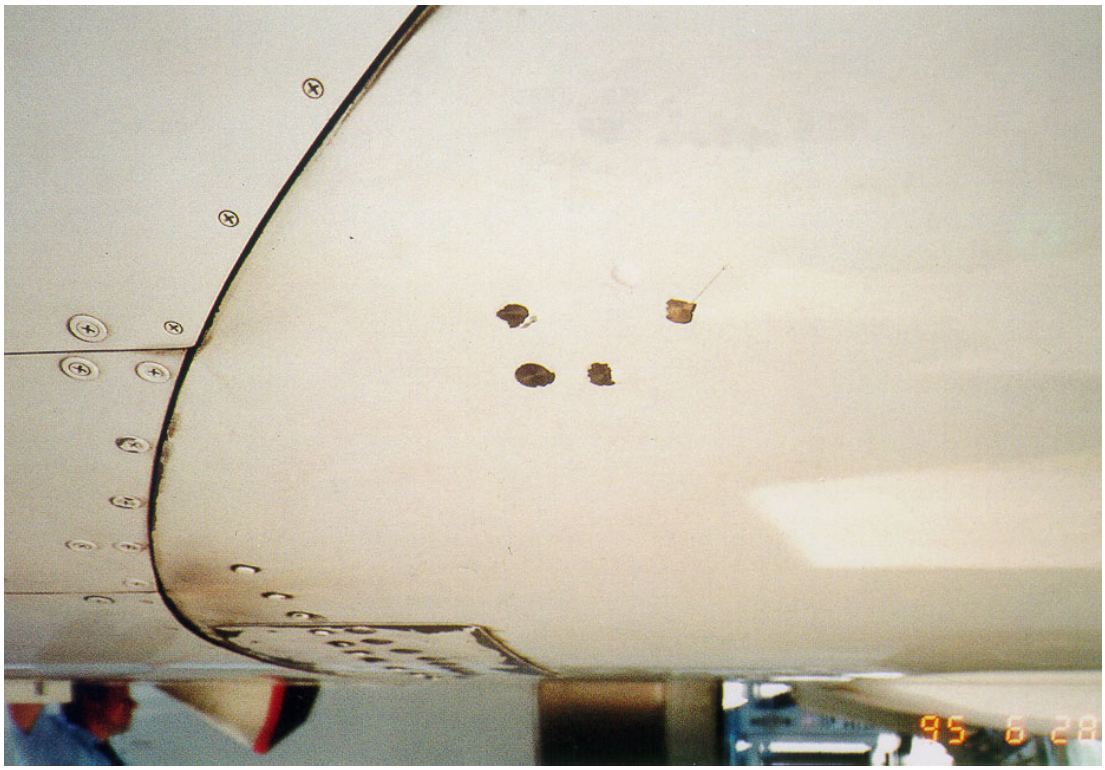
Paint peeling on the slat-
leading edge



Paint peeling on the belly
fairing



Paint peeling on the belly
fairing



5. A330/A340 FAMILY

5. A330/A340 FAMILY

The two aircraft of the long-range family have very similar airframes. Values given are best estimates for each aircraft.

As a simple rule, the higher the flight hours, the greater the effect of aerodynamic deterioration on fuel consumption. For that reason, assumptions about flight hours per year are very important and cause very considerable differences, depending on each individual case. Based on data reported by all Airbus operators the following flight hours (FH) per year per aircraft were assumed.

	FH / Year	Nominal Consumption US GAL / Year
A330	2,900 FH/year	19500
A340	4,700 FH/year	35700

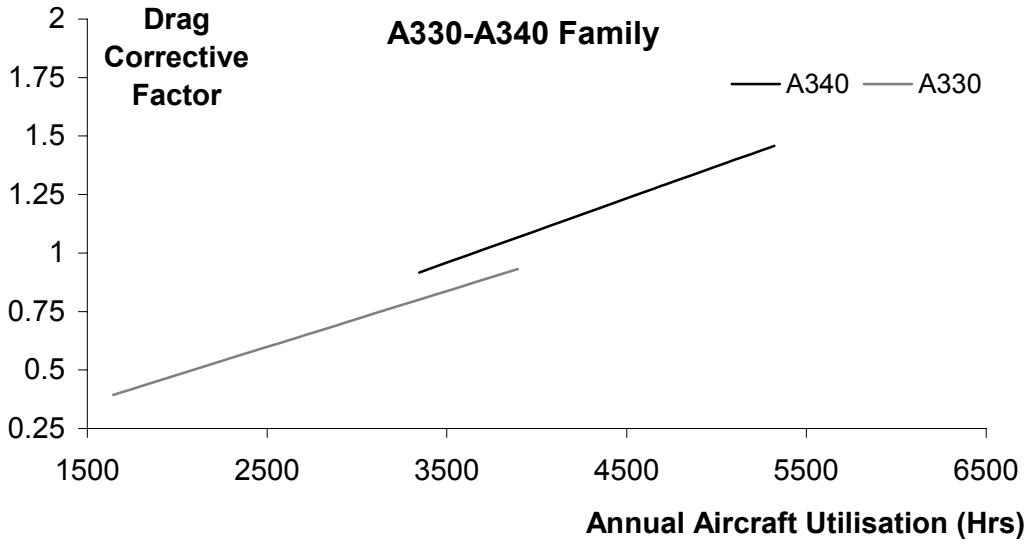
Drag penalty values each item are given in the tables from page 119 to 149, representing an average for the whole long-range family and have been determined considering a fictive airplane (representative of both A330 and A340 models) and which in average burns 27600 US Gallons / Year.

The manhours requested for each item is given as a guideline.

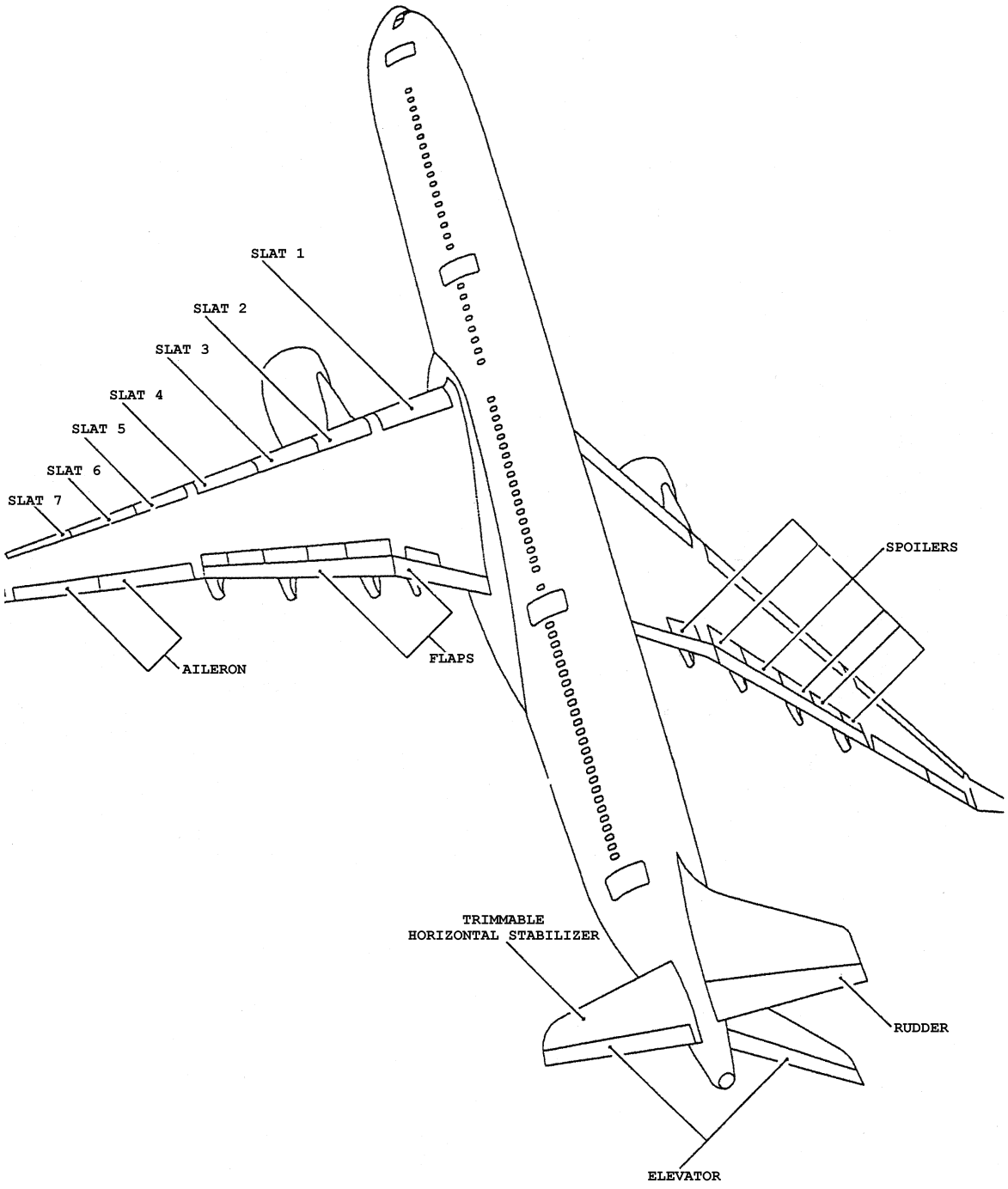
The accuracy is high enough to allow a comparison between the fuel burn penalties and the associated maintenance costs.

Corrective factor for drag penalty

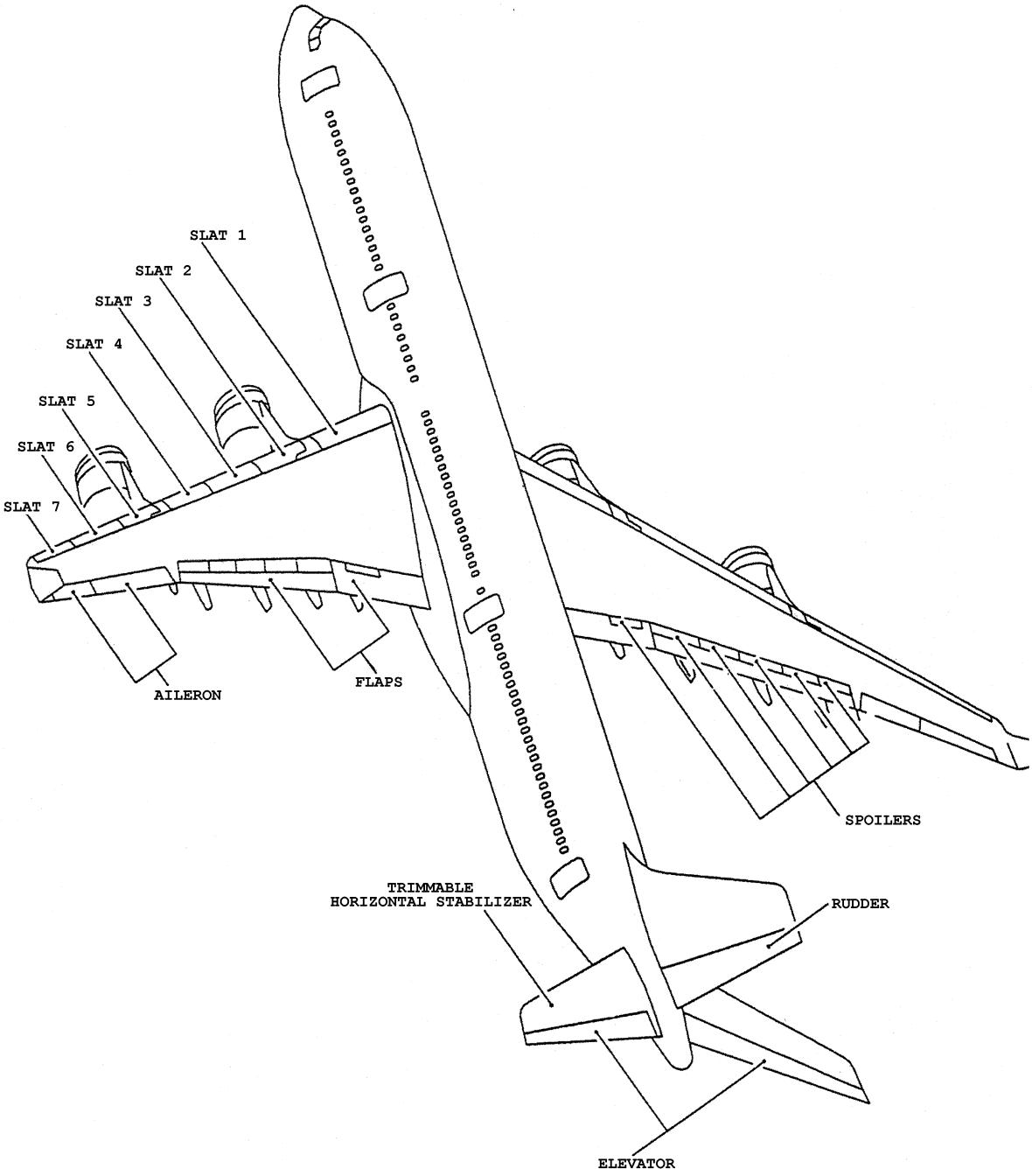
If there is a need to determine aircraft fuel penalties with greater accuracy and/or if the airline has a different aircraft utilisation, corrective factors to apply to the yearly fuel penalty (in US gallons or US$) can be introduced in relation to the annual aircraft utilisation. This corrective factor takes into account the drag penalties computed for the fictive airplane indicated above.



A330


SLAT 1
SLAT 2
SLAT 3
SLAT 4
SLAT 5
SLAT 6
SLAT 7
AILERON
FLAPS
SPOILERS
TRIMMABLE
HORIZONTAL STABILIZER
RUDDER
ELEVATOR

A340

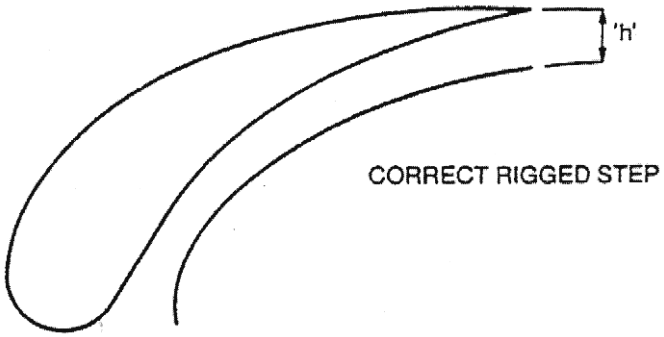

SLAT 1
SLAT 2
SLAT 3
SLAT 4
SLAT 5
SLAT 6
SLAT 7
AILERON
FLAPS
SPOILERS
TRIMMABLE
HORIZONTAL STABILIZER
RUDDER
ELEVATOR

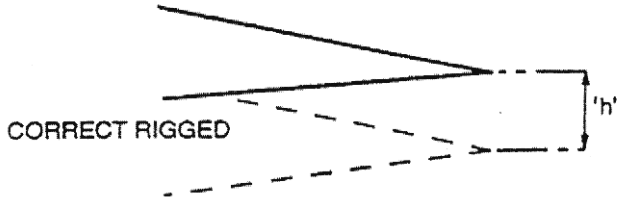
5.1 Misrigging on control surfaces

These items correspond to a specific control surface misrigging. The penalty is expressed by the difference in height at the control surface trailing edge between the misrigged and the correct position.

Slat

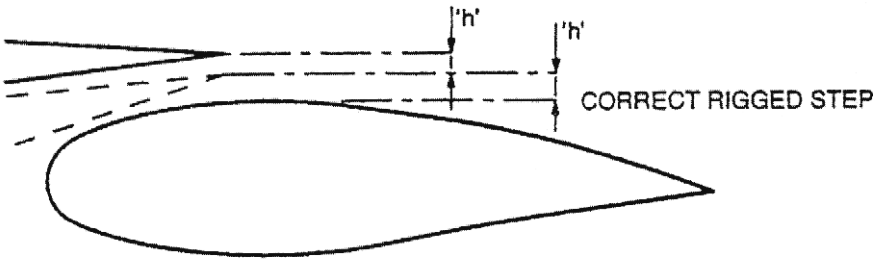
Flap



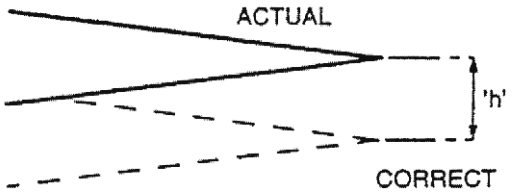


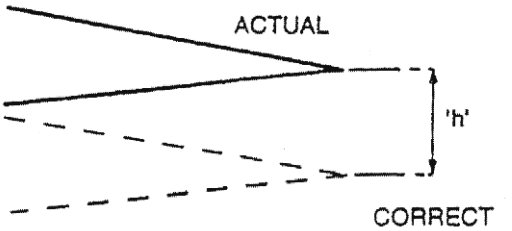
Spoiler

Aileron



Rudder

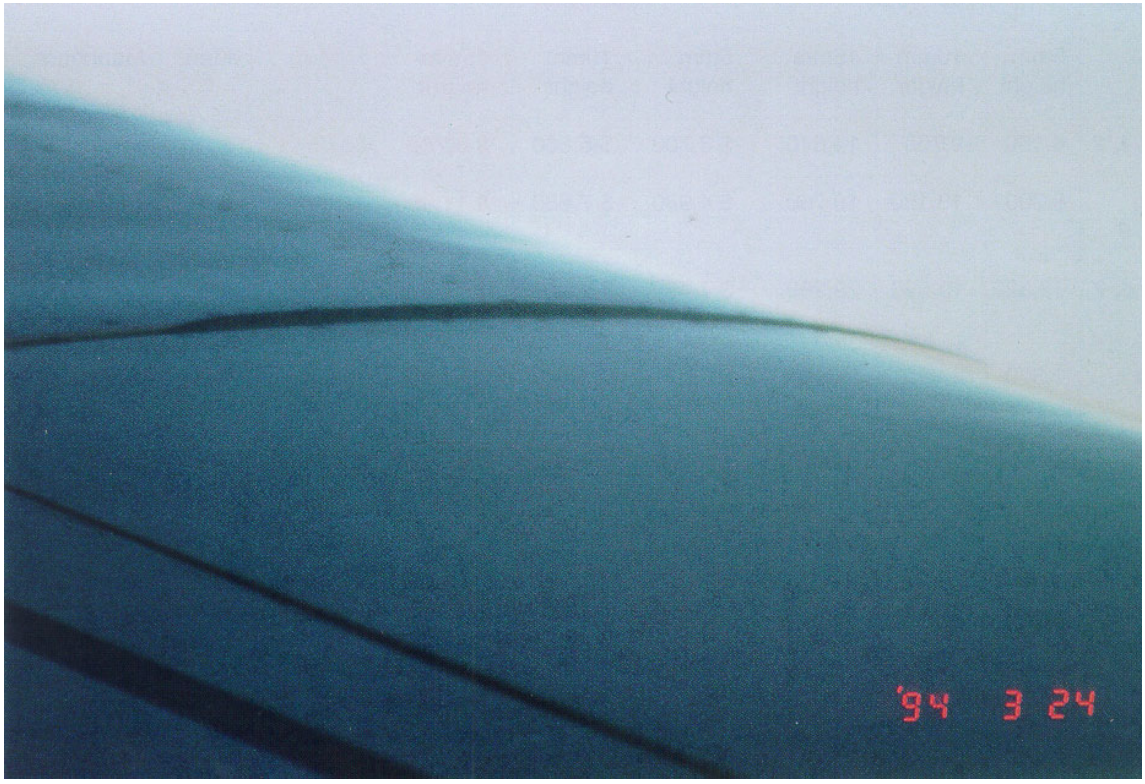




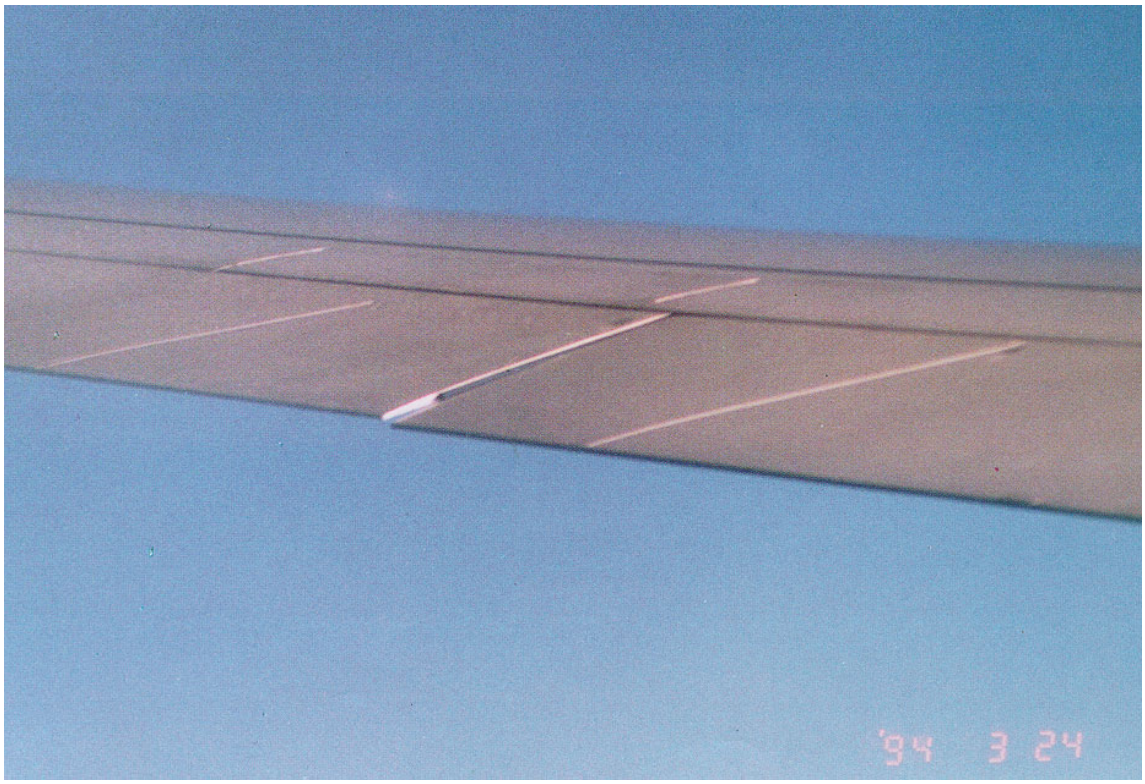
Control surface	Penalty in US gallons per year			Penalty in US $ per year			AMM reference	Corrective action		
	5mm height	10mm height	15mm height	5mm height	10mm height	15mm height		Men	Manhours	Cost
Slat 1, 2	6,160	9,760	14,640	$ 3,700	$ 5,860	$ 8,780	27 84 00	2	6	$ 300
Slat 3, 4, 5	8,300	13,150	19,700	$ 4,980	$ 7,830	$ 11,800	27 84 00	2	5	$ 250
Slat 6, 7	12,320	19,520	29,280	$ 7,400	$ 11,700	$ 17,600	27 84 00	2	5	$ 250
Flap	1,300	2,380	3,300	$ 780	$ 1,430	$ 1,980	27 54 00	2	8	$ 400
Spoiler	4,900	10,960	16,350	$ 2,940	$ 6,580	$ 9,810	27 64 00	1	2	$ 100
Aileron	1,300	2,400	3,400	$ 780	$ 1,440	$ 2,040	27 14 00	1	3	$ 150
Rudder	2,160	3760	5680	$ 1300	$ 2260	$ 3410	27 21 00	2	4	$ 200
Misalign -ment at flap track fairing	1,090	2180	2720	$ 650	$ 1300	$ 1630	05 25 30	2	5	$ 250

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Misrigged slat



Flap



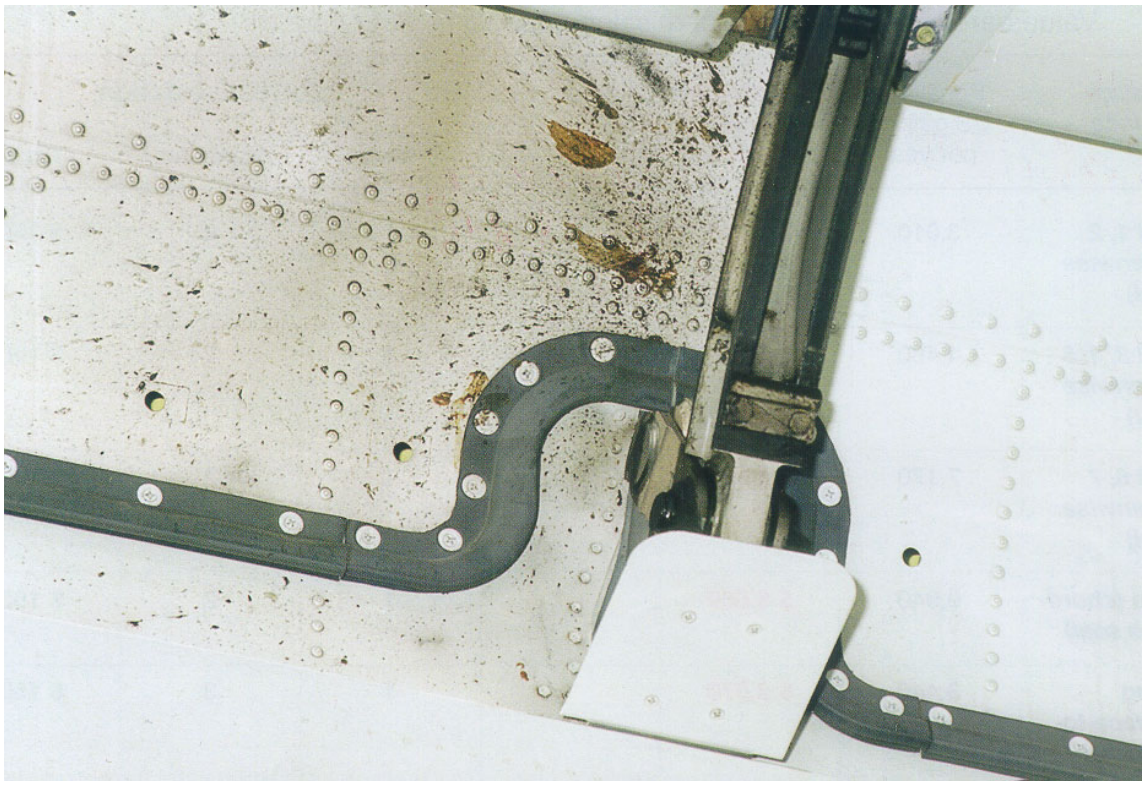
5.2 Absence of seals on movable sections

Values are given per meter of missing seal.

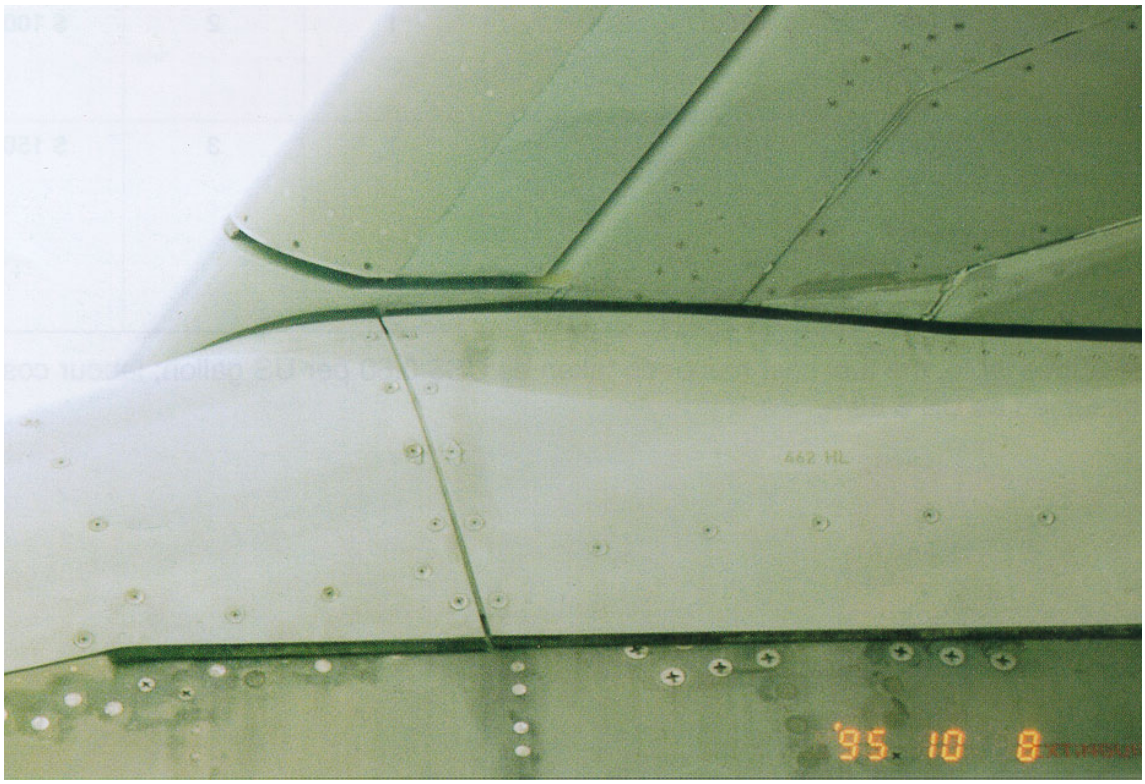
Control surface	Penalty in US gallons per year	**Penalty in US $ per year**	AMM reference	**Corrective action**		
				Men	Manhours	**Cost**
Slat 1, 2 (spanwise seal)	3,010	**$ 1,800**	27 84 71	1	2	**$ 100**
Slat 3, 4, 5 (spanwise seal)	4,480	**$ 2,690**	27 84 71	1	2	**$ 100**
Slat 6, 7 (spanwise seal)	7,170	**$ 4,300**	27 84 71	1	2	**$ 100**
Flap (chord-wise seal)	9,940	**$ 5,660**	27 54 72	1	2	**$ 100**
Wing surface-to-flap seal	3,440	**$ 2,070**	27 50 00	1	3	**$ 150**
Trailing edge missing from one spoiler	1,920	**$ 1,150**	27 64 00	1	2	**$ 100**
Aileron (chordwise seal)	9,440	**$ 5,660**	27 14 00 57 61 00	1	2	**$ 100**
Fairing and rubber seal missing from fin/fuselage junction	1,160	**$ 6,950**	27 21 41	1	3	**$ 150**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

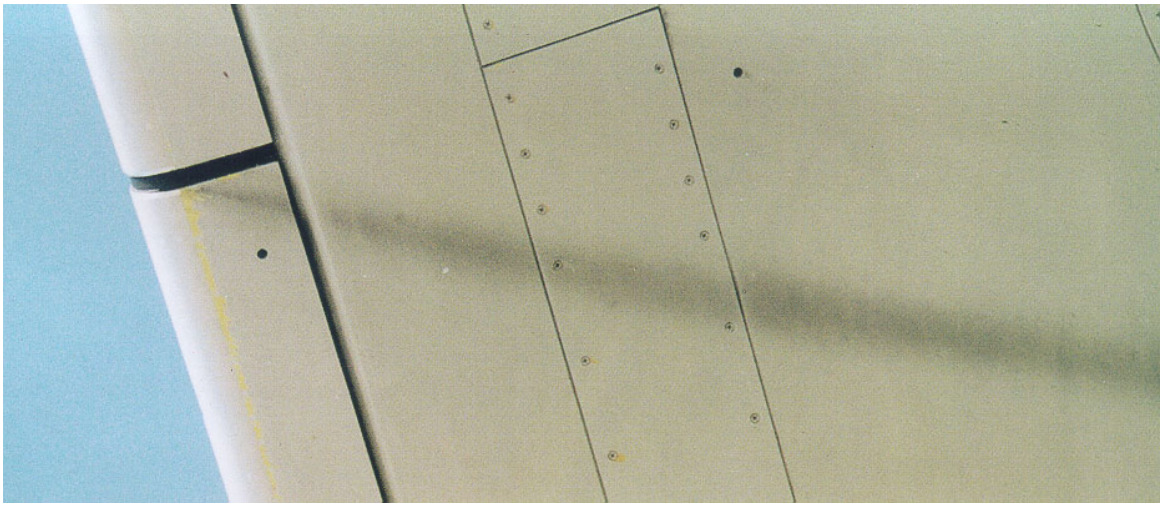
Spanwise slat seal



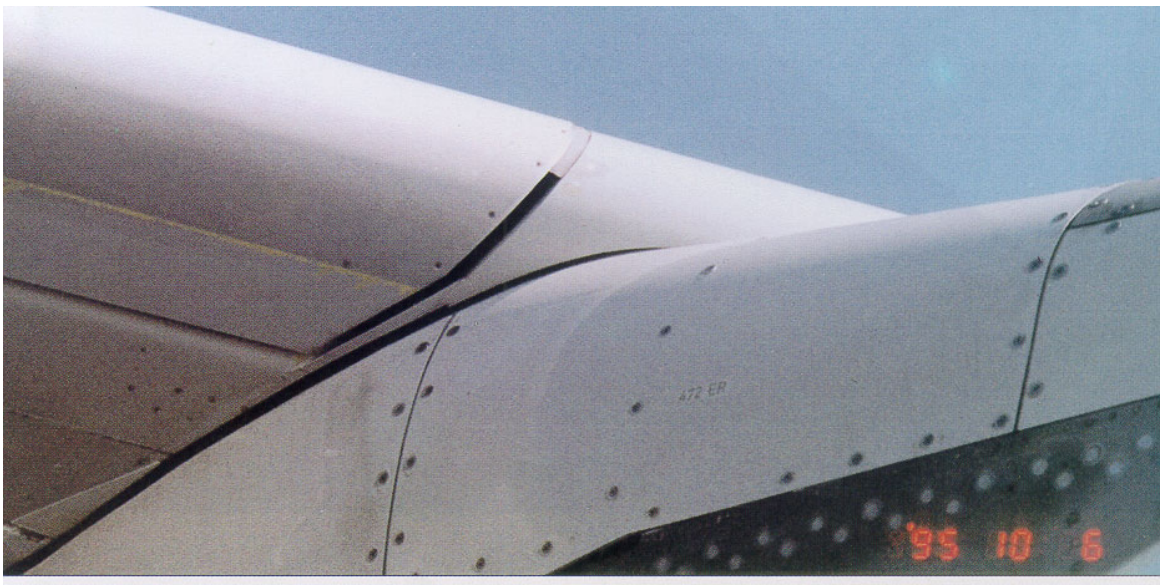
Missing chordwise slat seal



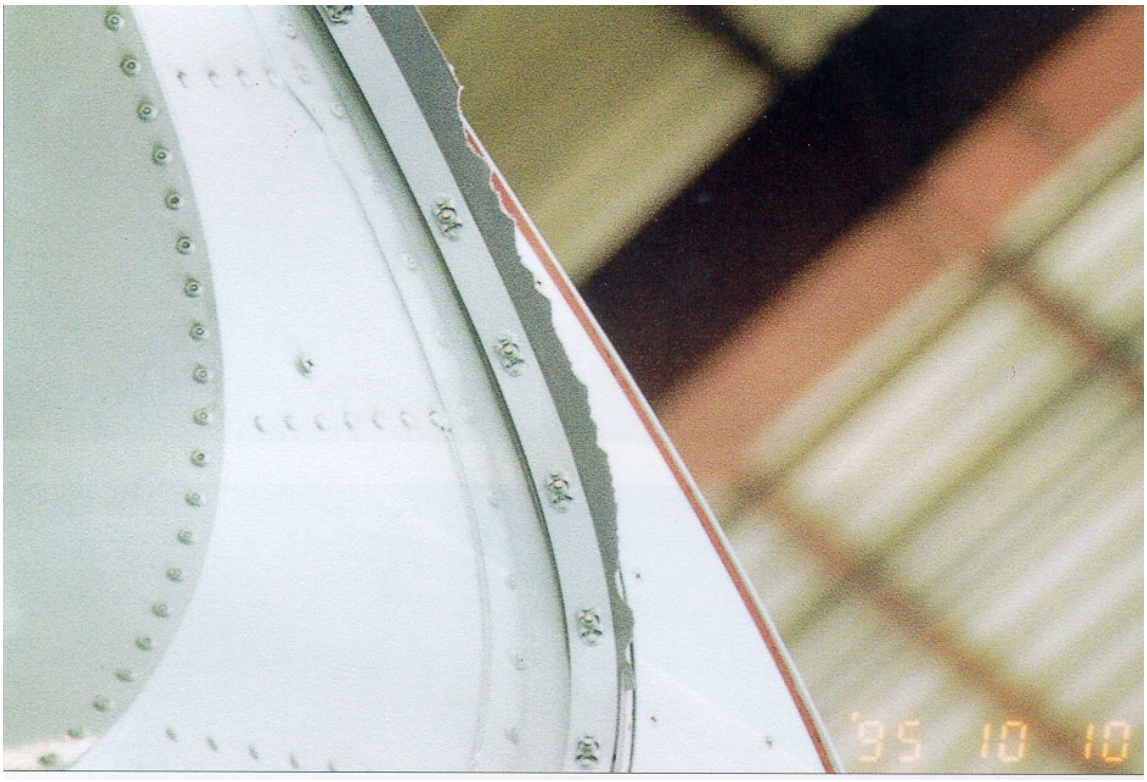
Missing spanwise slat seal



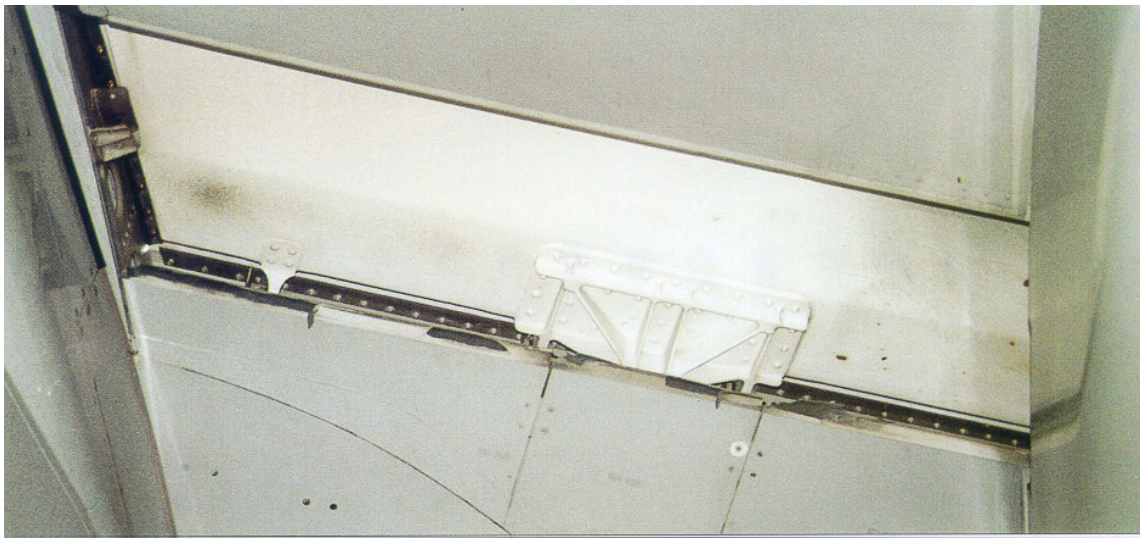
Missing chordwise seal

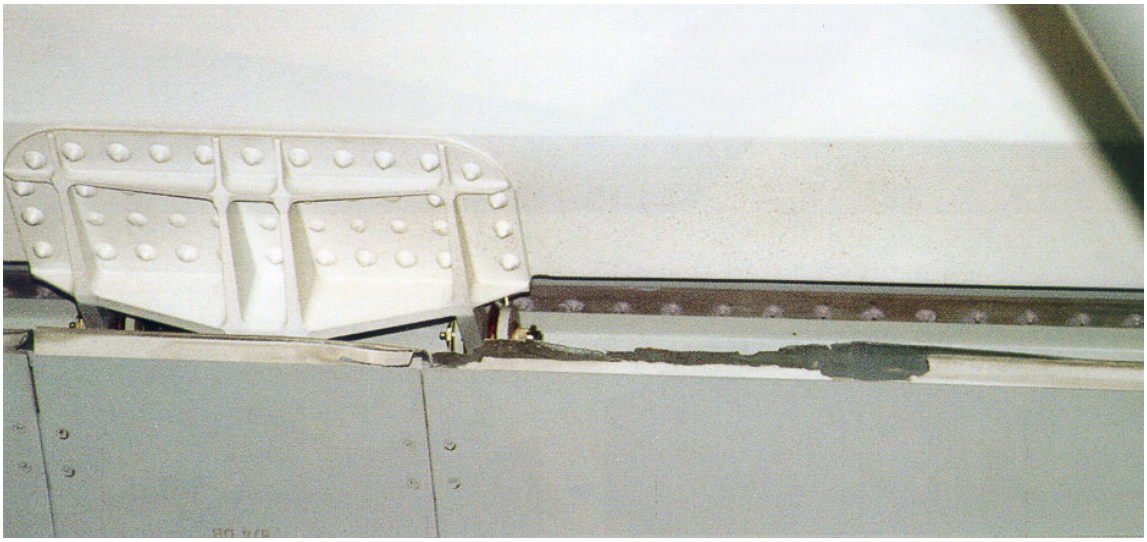


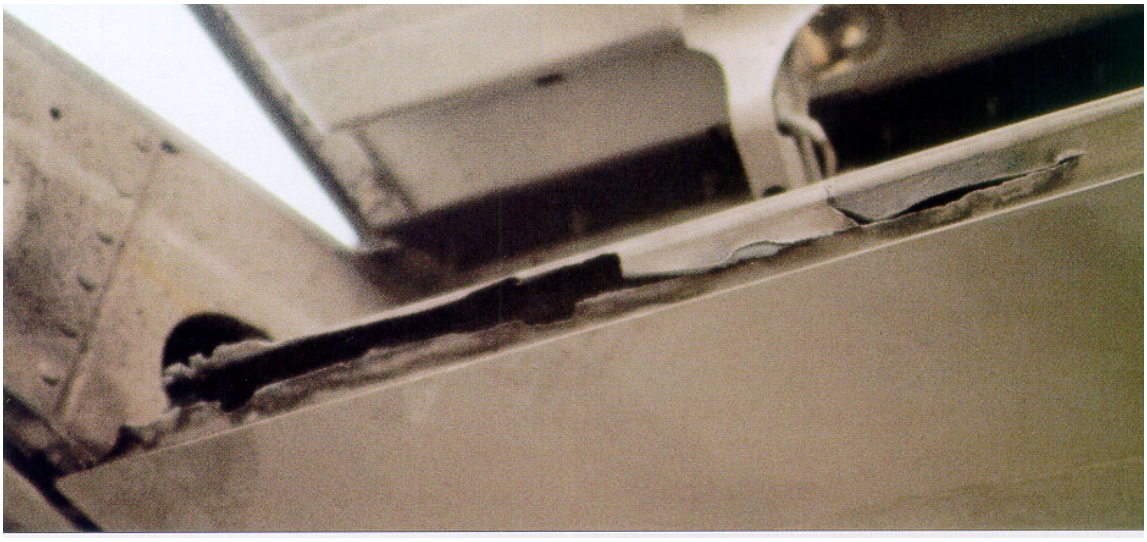
Damaged chordwise slat seal



Damaged wing lower-surface-to-flap seals



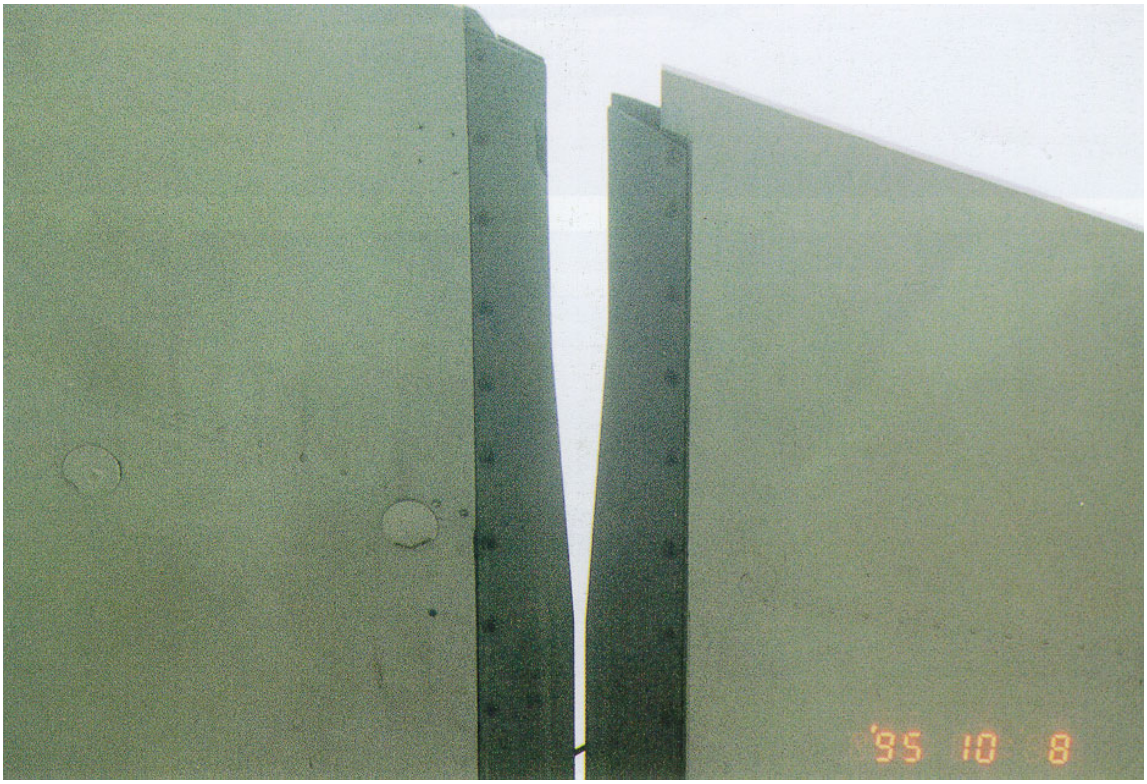


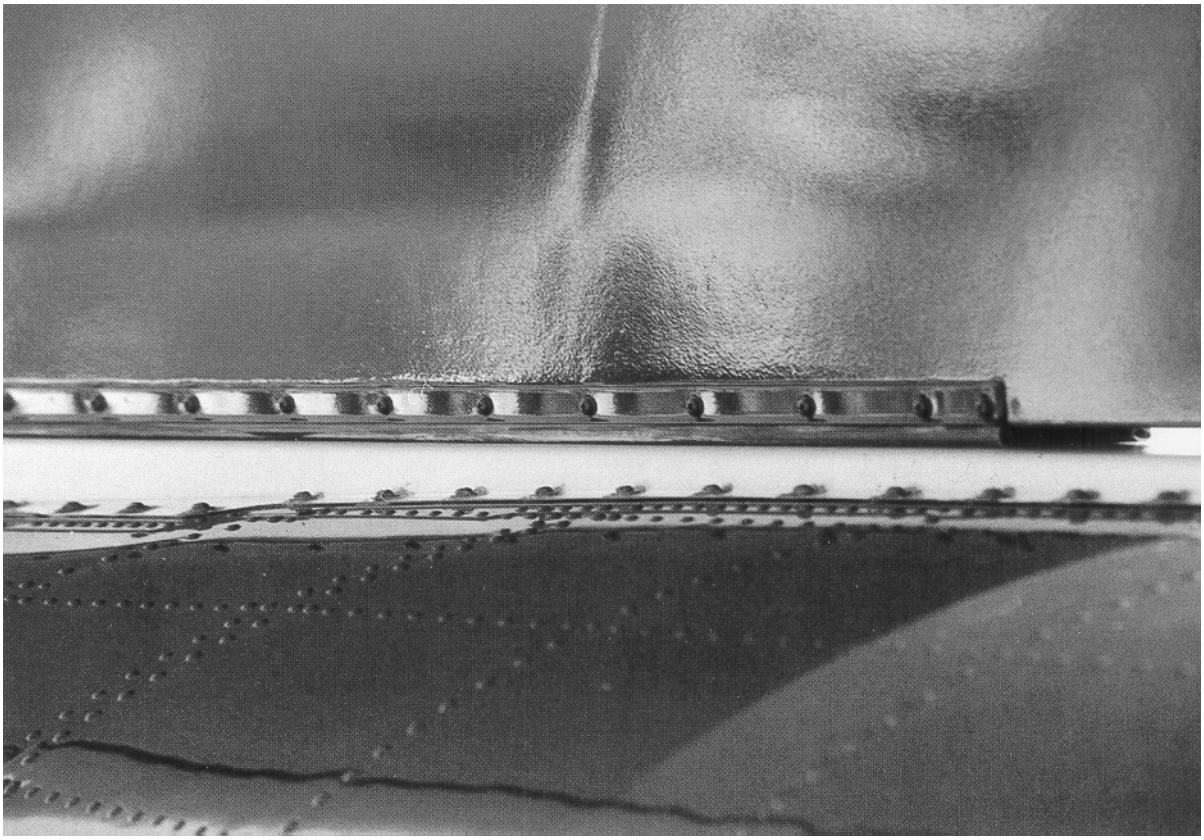


Missing aileron

spanwise seal

Chordwise flap seal





Rubber seal on the
fin/fuselage junction

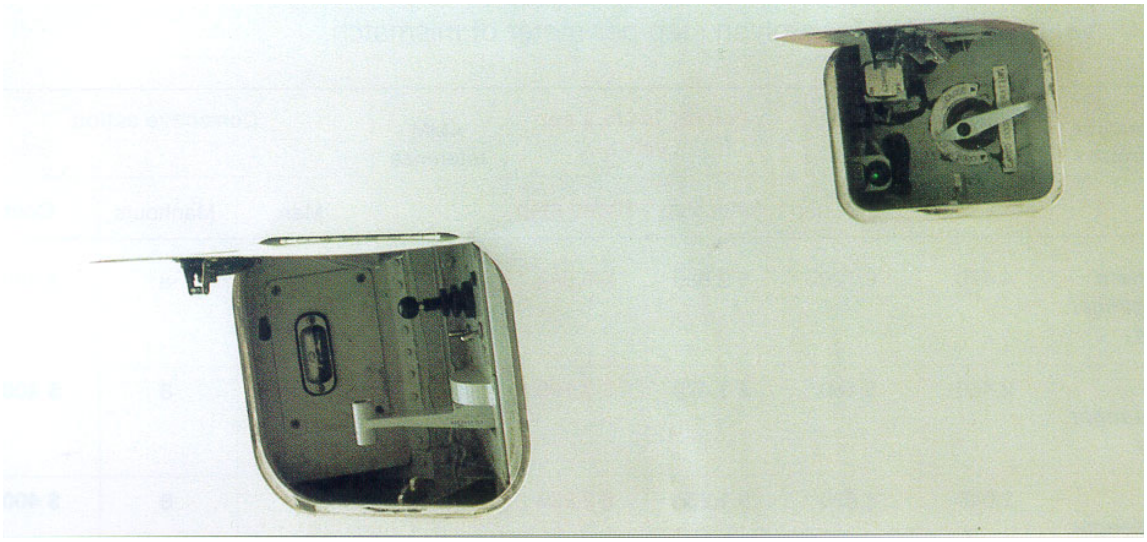
5.3 Missing parts

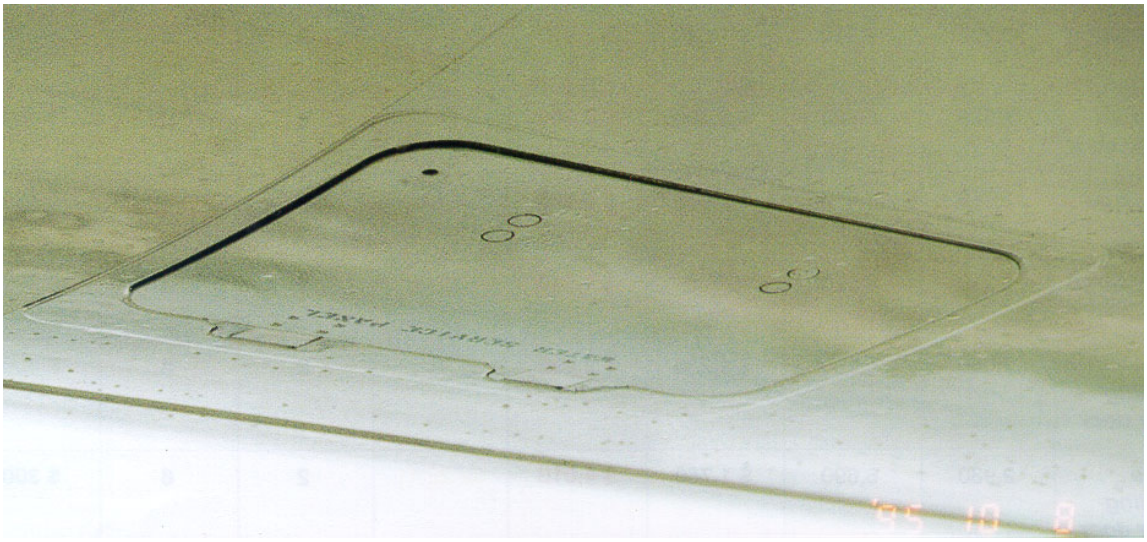
Values are given per meter of missing part.

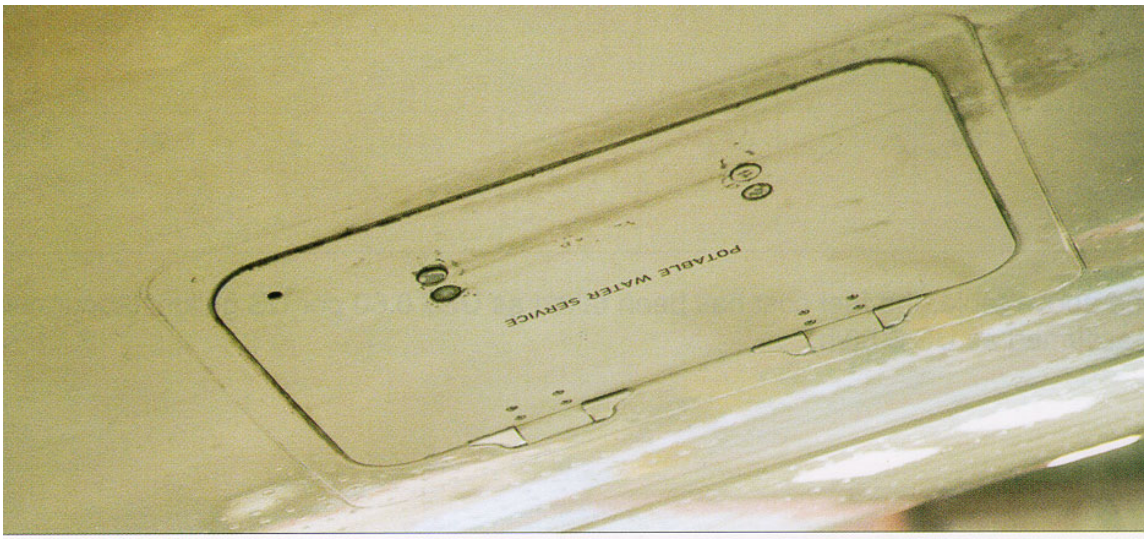
Missing part	Penalty in US gallons per year	**Penalty in US $ per year**	AMM reference	**Corrective action**		
				Men	Manhours	**Cost**
Access door in the fuselage Zone 1 area	16,320	**$ 9,800**	52 41 00 52 42 00	1	4	**$ 200**
Access door in the fuselage Zone 2 area	12,240	**$ 7,340**	52 41 00 52 42 00	1	4	**$ 200**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Service doors







5.4 Mismatched surfaces

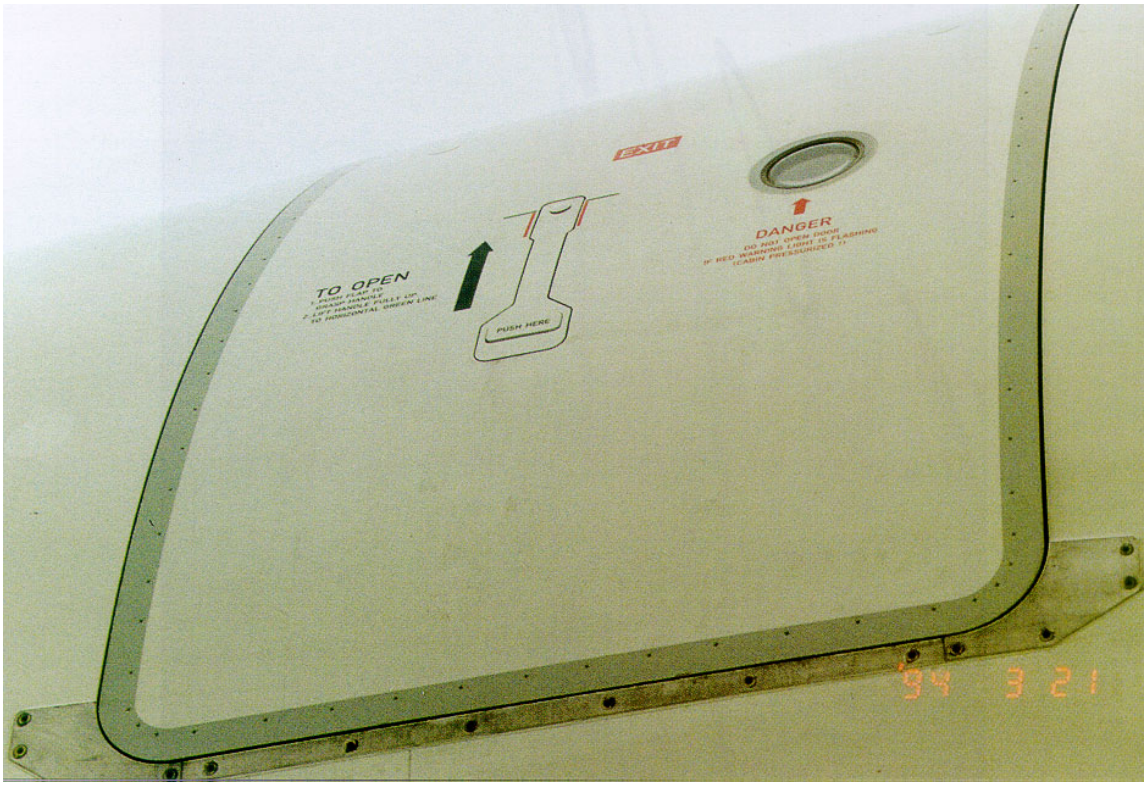
Values are given for a given per meter of mismatch.

Mismatched surface	Penalty in US gallons per year		**Penalty in US $ per year**		AMM reference	**Corrective action**		
	5mm step	10mm step	5mm step	10mm step		Men	Manhours	**Cost**
Forward passenger door	4,470	8,720	$ 2,680	**$ 5,330**	52 11 00	2	8	**$ 400**
Mid passenger door	2,460	5,160	$ 1,470	**$ 3,100**	52 12 00	2	8	**$ 400**
Aft passenger door	2,040	4,690	$ 1,230	**$ 2,820**	52 13 00	2	8	**$ 400**
Emergency exit	2,230	4,860	$ 1,340	**$ 2,920**	52 22 00	2	8	**$ 400**
Forward cargo door	4,526	8,830	$ 2,720	**$ 5,300**	52 31 00	2	13	**$ 650**
Aft cargo door	2,760	5,410	$ 1,660	**$ 3,250**	52 32 11	2	13	**$ 650**
Bulk cargo door	1,210	2,570	$ 730	**$ 1,540**	52 33 11	1	4	**$ 200**
Main landing gear door	2,050	5,150	$ 1,230	**$ 3,090**	32 12 11	2	8	**$ 400**
Nose landing gear door	2,930	6,690	$ 1,760	**$ 4,010**	32 22 11	2	6	**$ 300**
Access door in Zone 1 area	1,160	3,140	$ 700	**$ 1,880**	no adjustment procedure			
Radome misfit (maximum allowed)	1,270		**$ 760**		53 10 00	2	7	**$ 350**

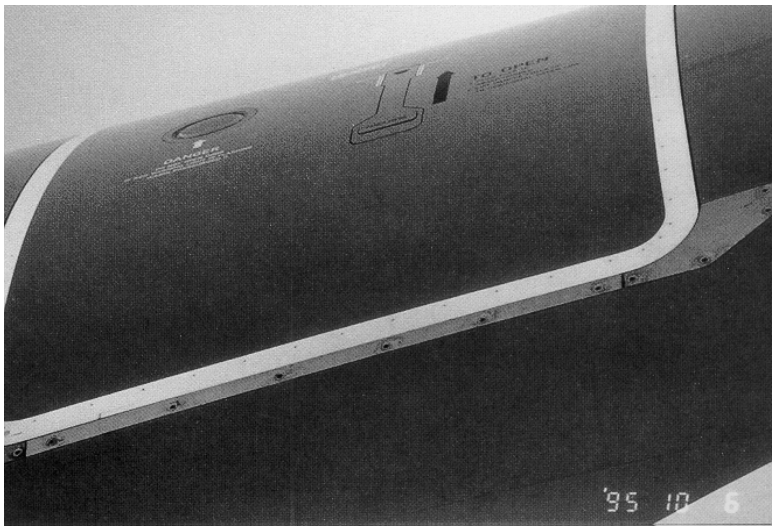
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

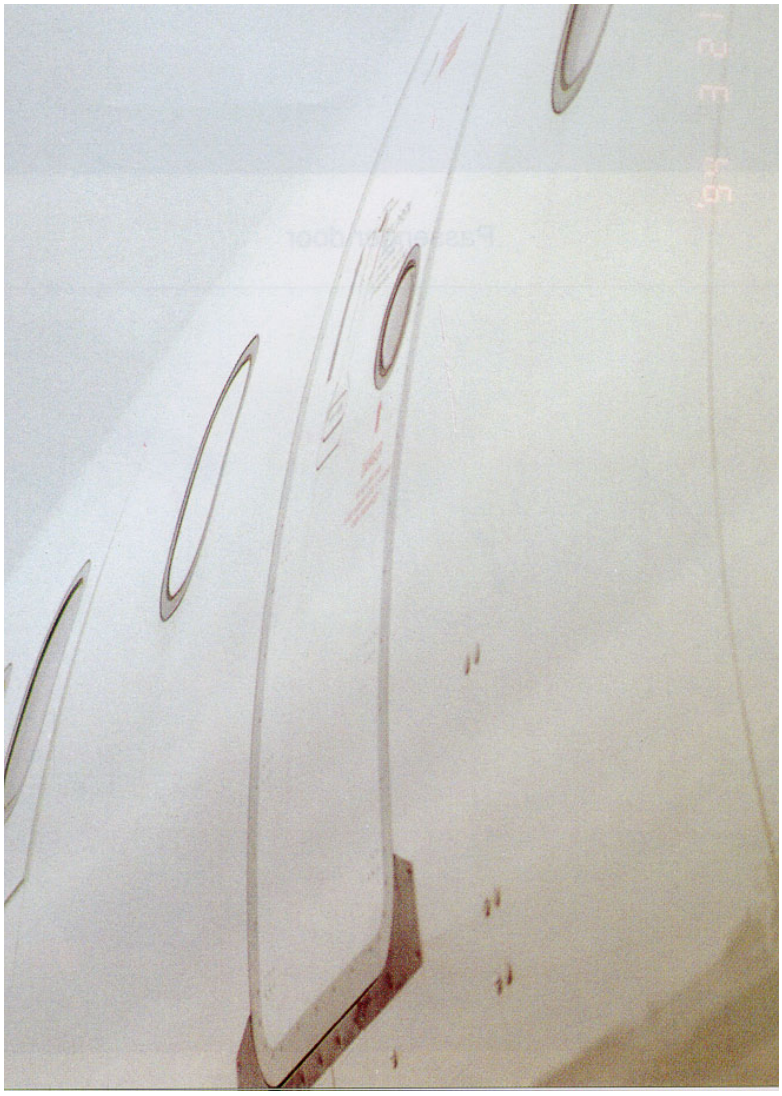
Passenger door

Passenger door

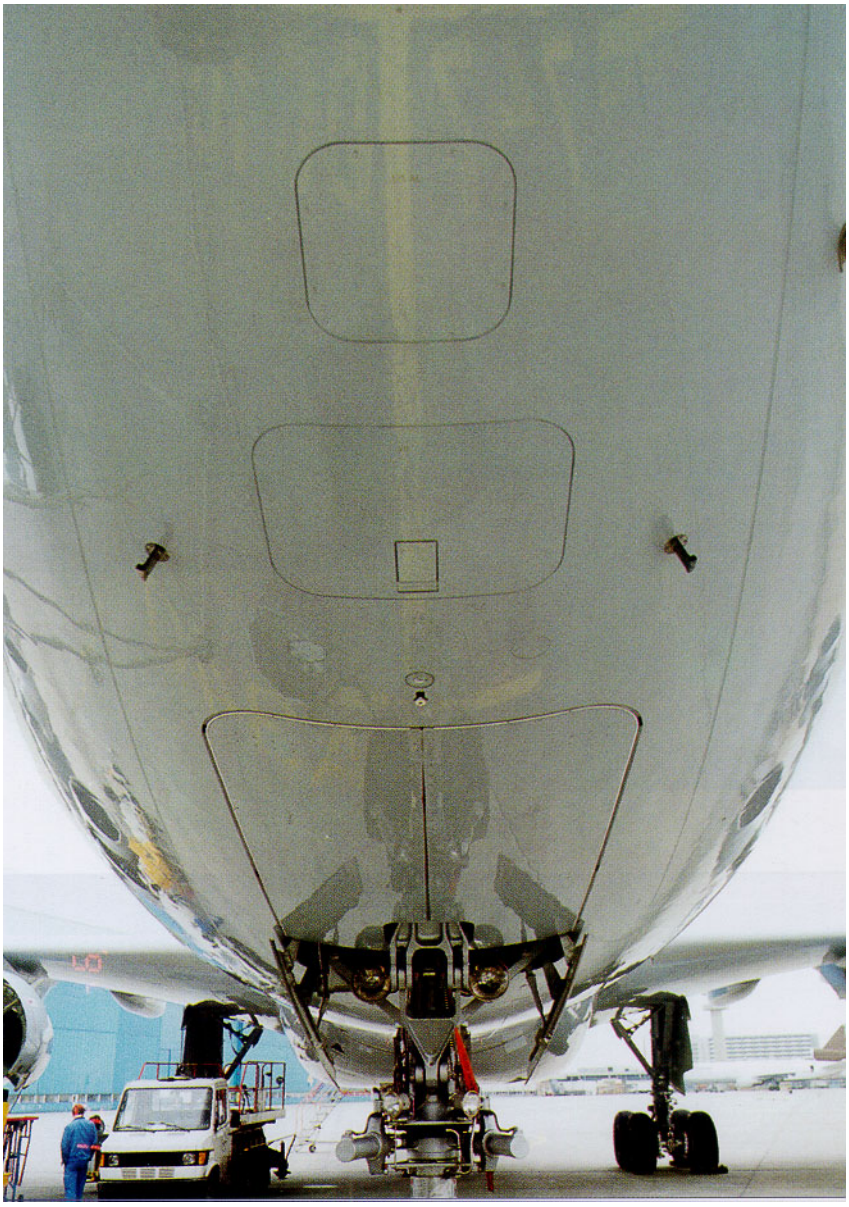


Mismatched passenger door

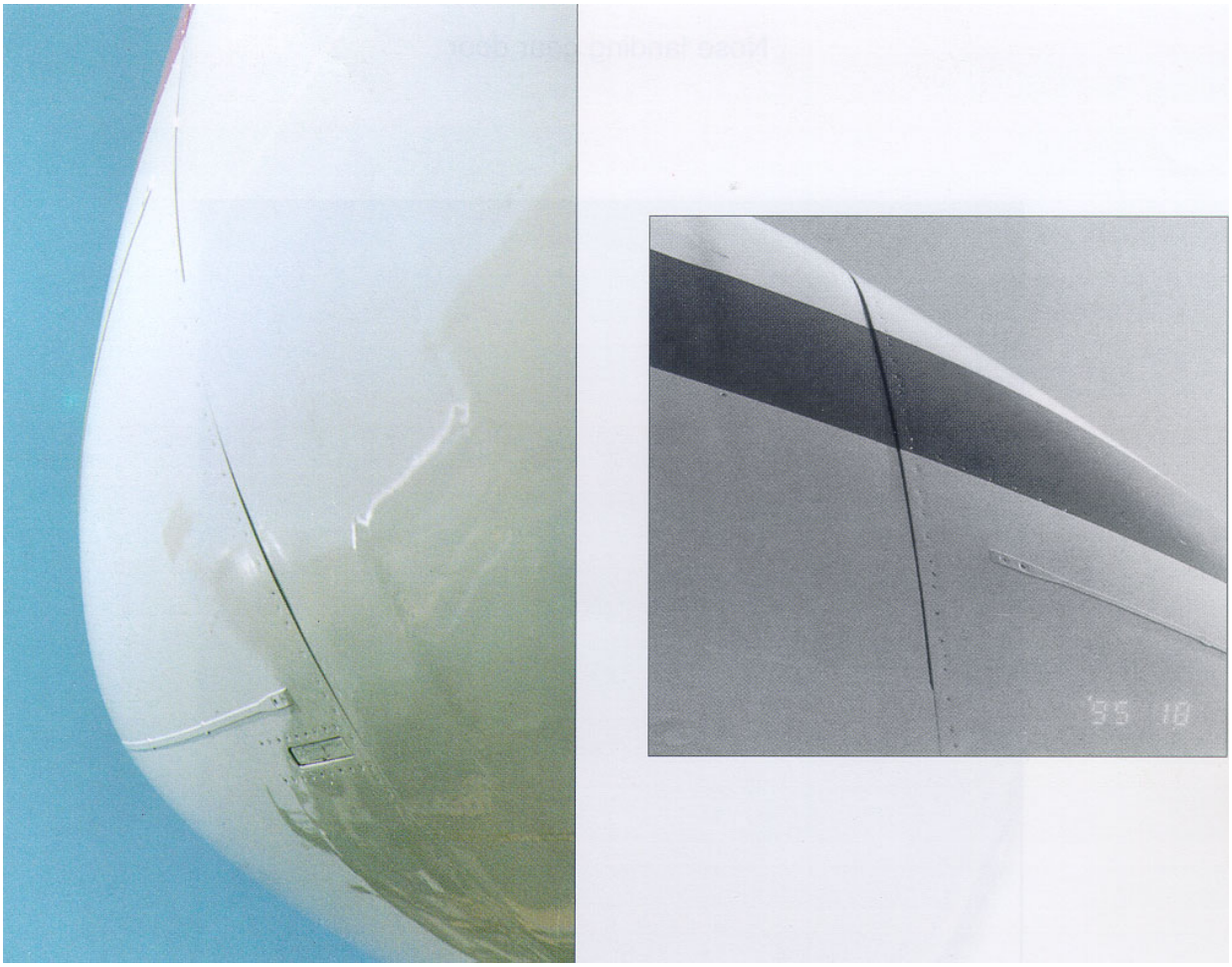




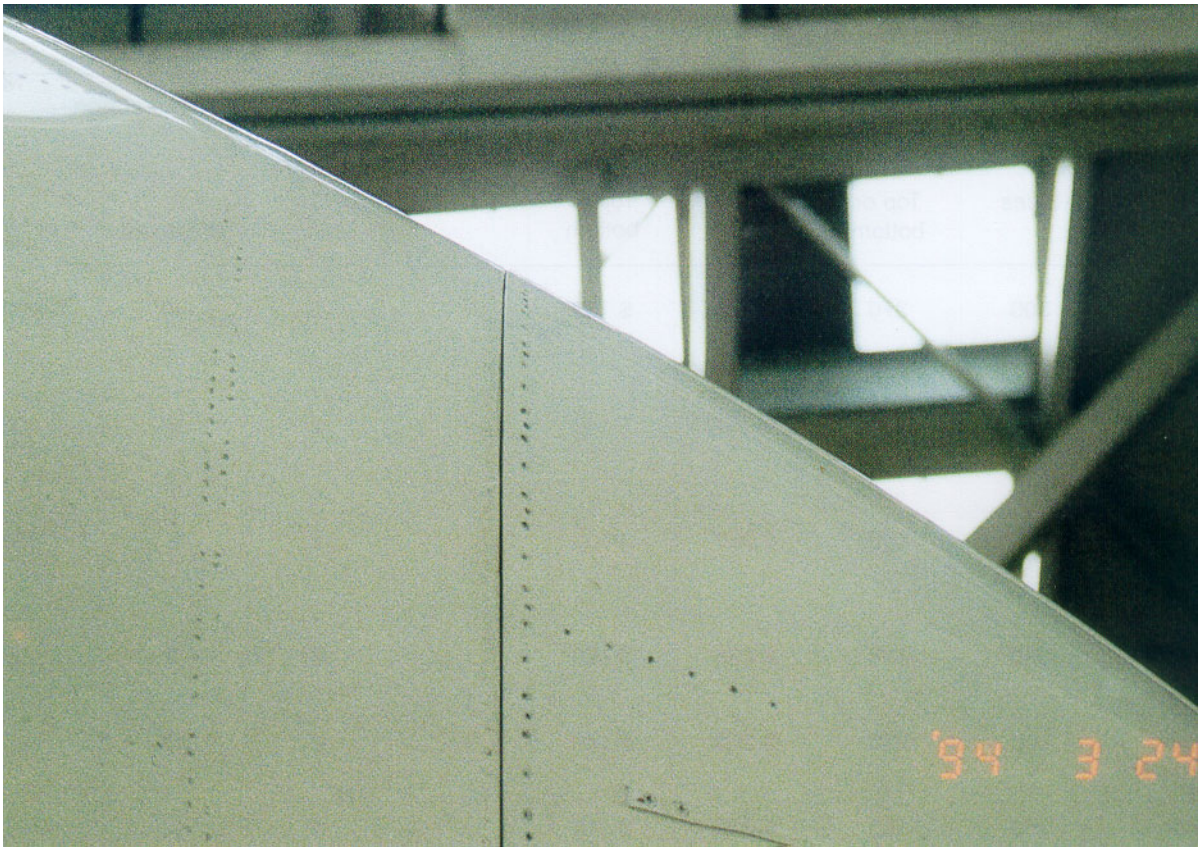
Nose landing gear door



Radome misfit



Radome misfit



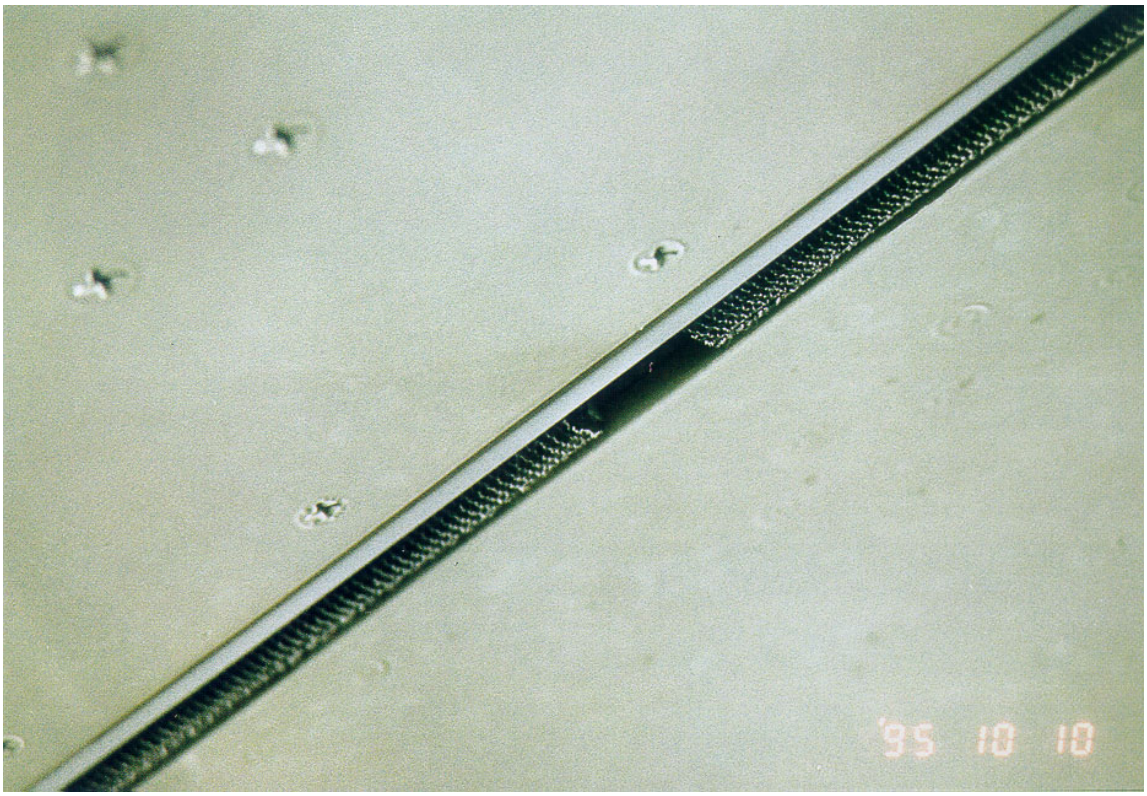
5.5 Door seal leakage

Values are given for a 5cm damaged door seal section.

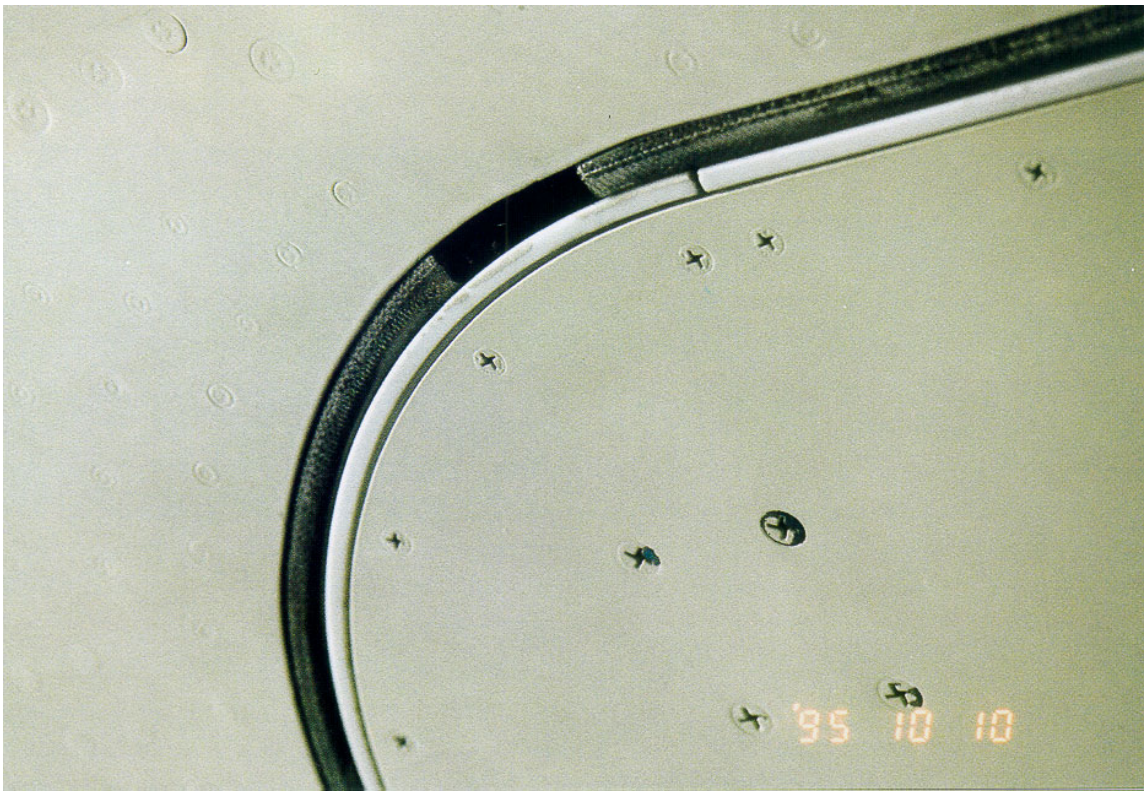
Item	Penalty in US gallons per year		**Penalty in US $ per year**		AMM reference	**Corrective action**		
	Sides	Top or bottom	**Sides**	**Top or bottom**		Men	Manhours	**Cost**
Forward passenger door	500	270	**$ 300**	$ 160	52 11 18	2	8	**$ 400**
Mid passenger door	420	240	**$ 250**	$ 140	52 12 18	2	8	**$ 400**
Aft passenger door	370	190	**$ 220**	$ 120	52 13 18	2	8	**$ 400**
Emergency exit	380	190	**$ 230**	$ 120	52 22 18	2	8	**$ 400**
Forward cargo door	460	240	**$ 280**	$ 140	52 31 18	2	13	**$ 650**
Aft cargo door	350	180	**$ 210**	$ 110	52 32 18	2	13	**$ 650**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

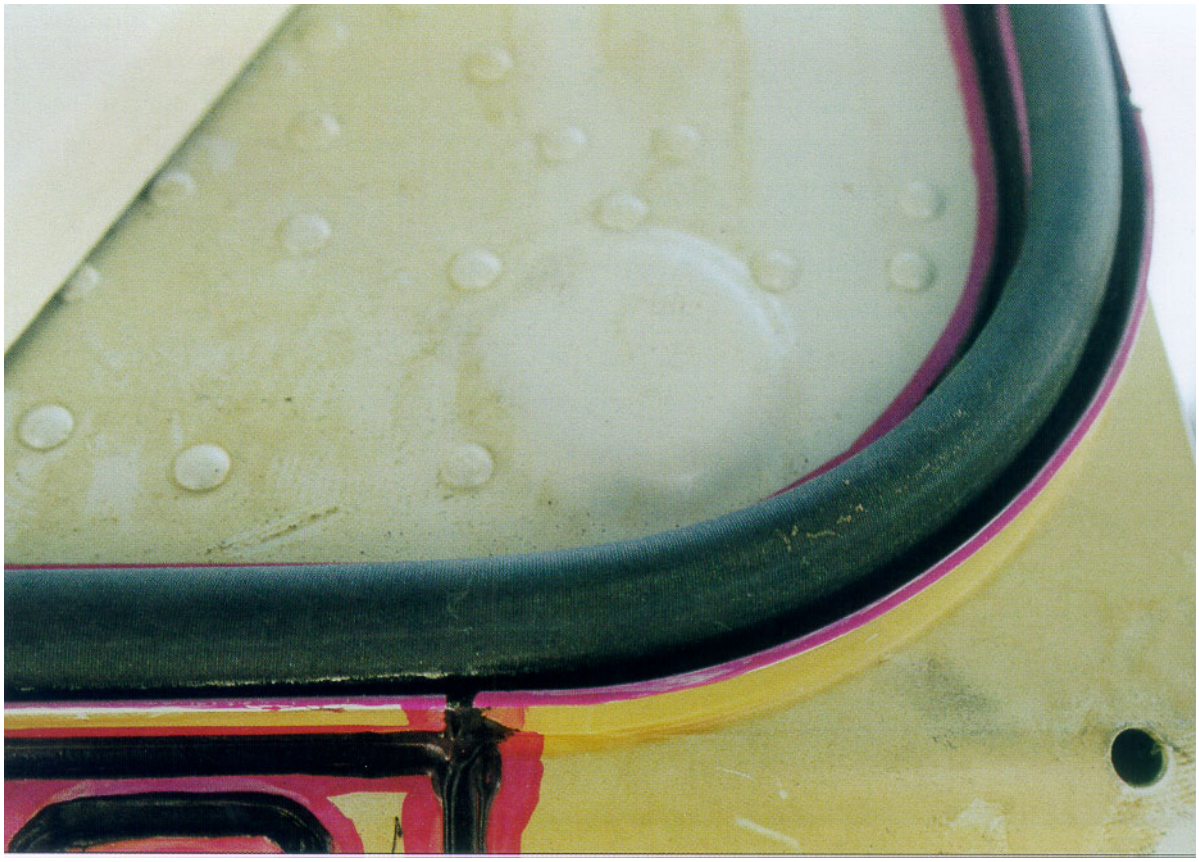
Missing door seal



Missing door seal



Door seal



5.6 Surface deterioration

5.6.1 Skin roughness

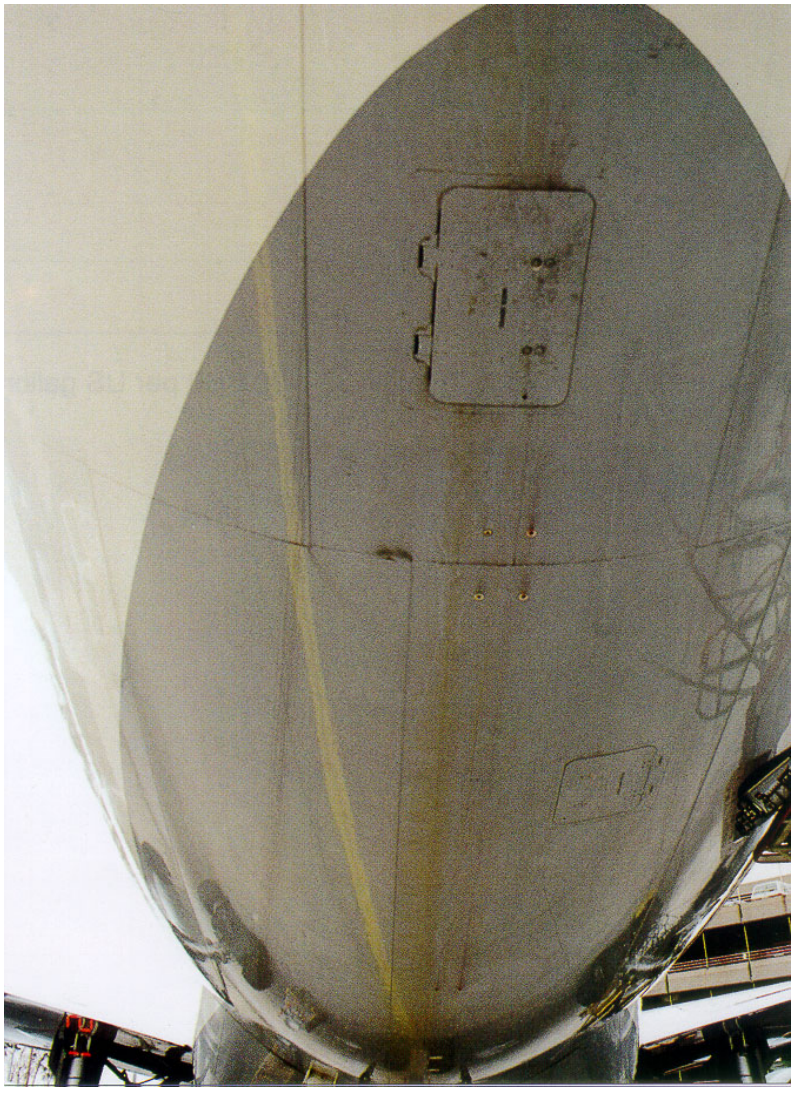
Values are given for a 0.3mm skin roughness height over a $1m^2$ area in Zone 1.

Affected area	Penalty in US gallons per year	**Penalty in US $ per year**	Maintenance reference	**Corrective action**		
			SRM 51 10 00	Men	Manhours	**Cost**
Leading edge slat	11,500	**$ 6,900**	External cleaning AMM 12 21 11 AMM 51 78 00	1	1	**$ 50**
Wing skin – upper	7,120	**$ 4,270**	Polishing AMM 51 21 00	1	3	**$ 150**
Wing skin – lower	3,560	**$ 2,140**				
Tail	2,460	**$ 1,470**				
Fuselage	1,300	**$ 780**				

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

For Zone 2, divide the above values by 1.3.

Skin roughness



5.6.2 Skin dents

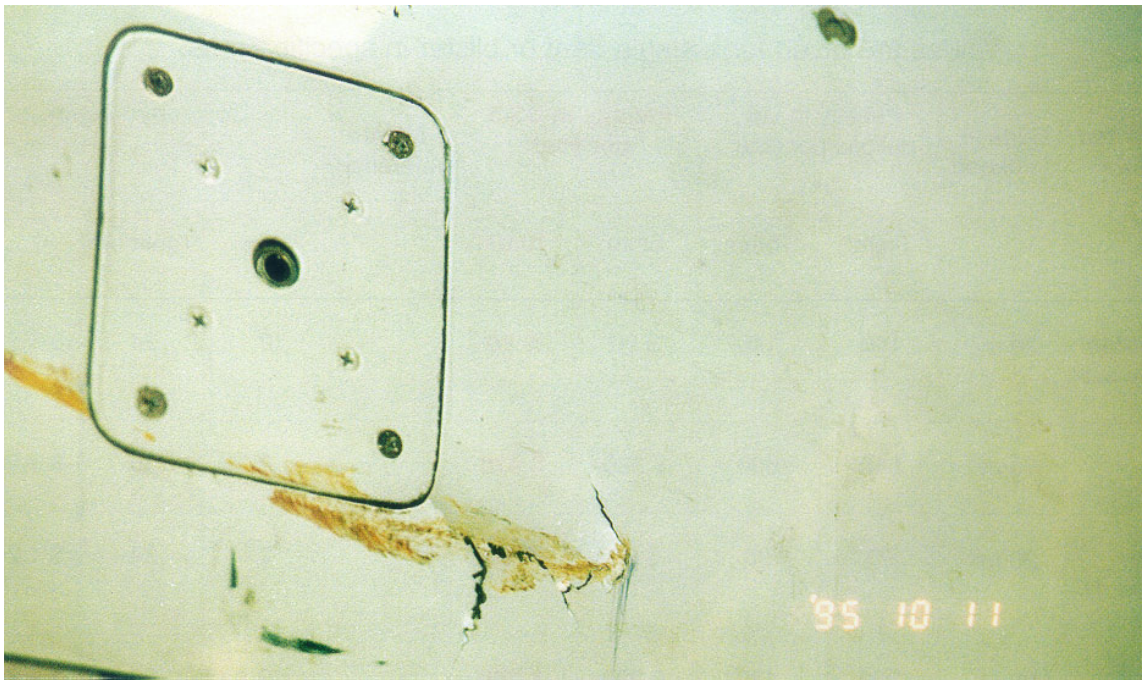
Values are given for a single dent or blister in specific areas.

Affected area	Surface dama-ged	Penalty in US gallons per year		Penalty in US $ per year		Maint. reference	Corrective action		
		5mm	10mm	5 mm	10 mm	SRM 51 73 00 AMM 51 73 11	Men	Manhours	Cost
Leading edge slat	20 m^2	140	140	$ 90	**$ 90**	27 80 00	2	24	**$ 1,200**
	80 m^2	640	690	$ 380	**$ 420**		2	60	**$ 3,000**
Wing (Zone 1)	20 m^2	90	90	$ 50	**$ 50**	57 00 00	2	24	**$ 1,200**
	80 m^2	390	430	$ 230	**$ 260**		2	60	**$ 3,000**
Tail (Zone 1)	20 m^2	39	52	$ 23	**$ 31**	55 00 00	2	24	**$ 1,200**
	80 m^2	97	190	$ 58	**$ 114**		2	40	**$ 2,000**
Fuselage (Zone 2)	20 m^2	11	14	$ 7	**$ 8**	53 00 00	2	16	**$ 800**
	80 m^2	28	28	$ 17	**$ 17**		2	40	**$ 2,000**
Scuff plate at forward pax door		170	430	$ 100	**$ 260**	AMM 53 45 15	1	1	**$ 50**
Scuff plate at forward cargo door		160	410	$ 100	**$ 250**	AMM 53 45 15	1	1	**$ 50**
Scuff plate at bulk door		90	230	$ 50	**$ 140**	AMM 53 45 15	1	1	**$ 50**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

For the fuselage Zone 1 areas, multiply the above values by 1.51
For the wing Zone 2 areas, divide the above values by 1.23
For the tail Zone 2 areas, divide the above values by 1.17

Dented skin



Dented scuff plates

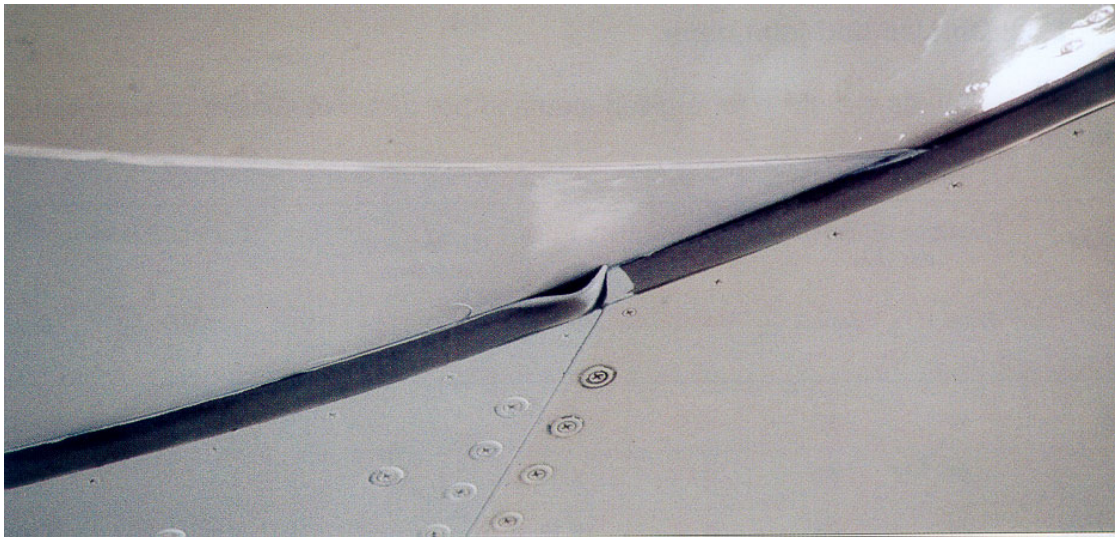
5.6.3 Unfilled butt joint gaps

Values are given for a given step and per meter of sealant of gap 2mm and width 5mm.

Affected area	Penalty in US gallons per year		**Penalty in US $ per year**		Maintenance reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Wing	47	37	**$ 28**	$ 22		1	2	**$ 100**
Tail	68	51	**$ 41**	$ 30		1	2	**$ 100**
Fuselage	29	20	**$ 17**	$ 12	SRM 51 76 11	1	2	**$ 100**

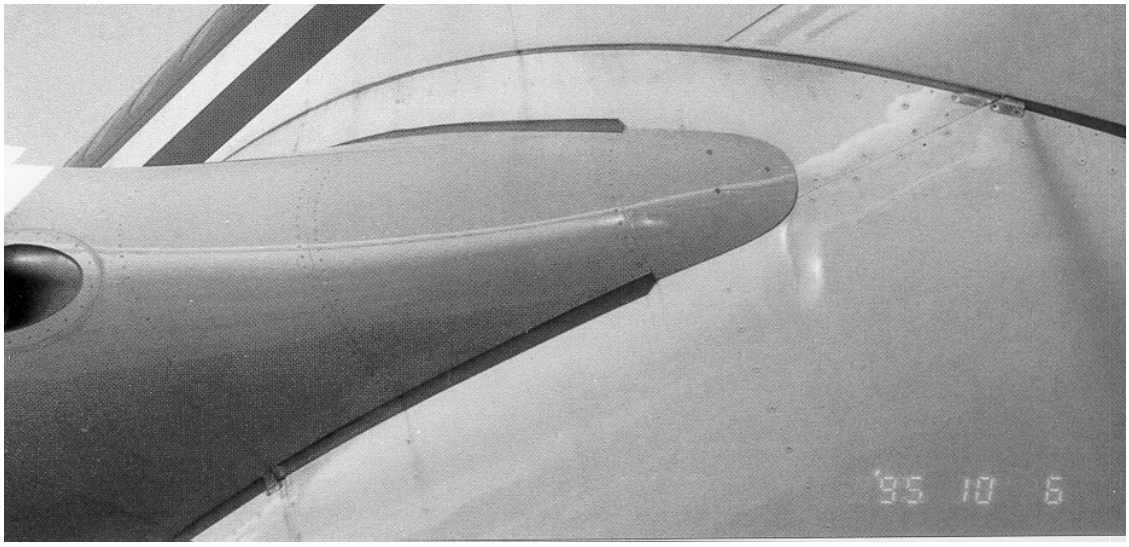
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Damaged seal



Missing seal

Missing seal



5.7 Consequences of hasty repairs

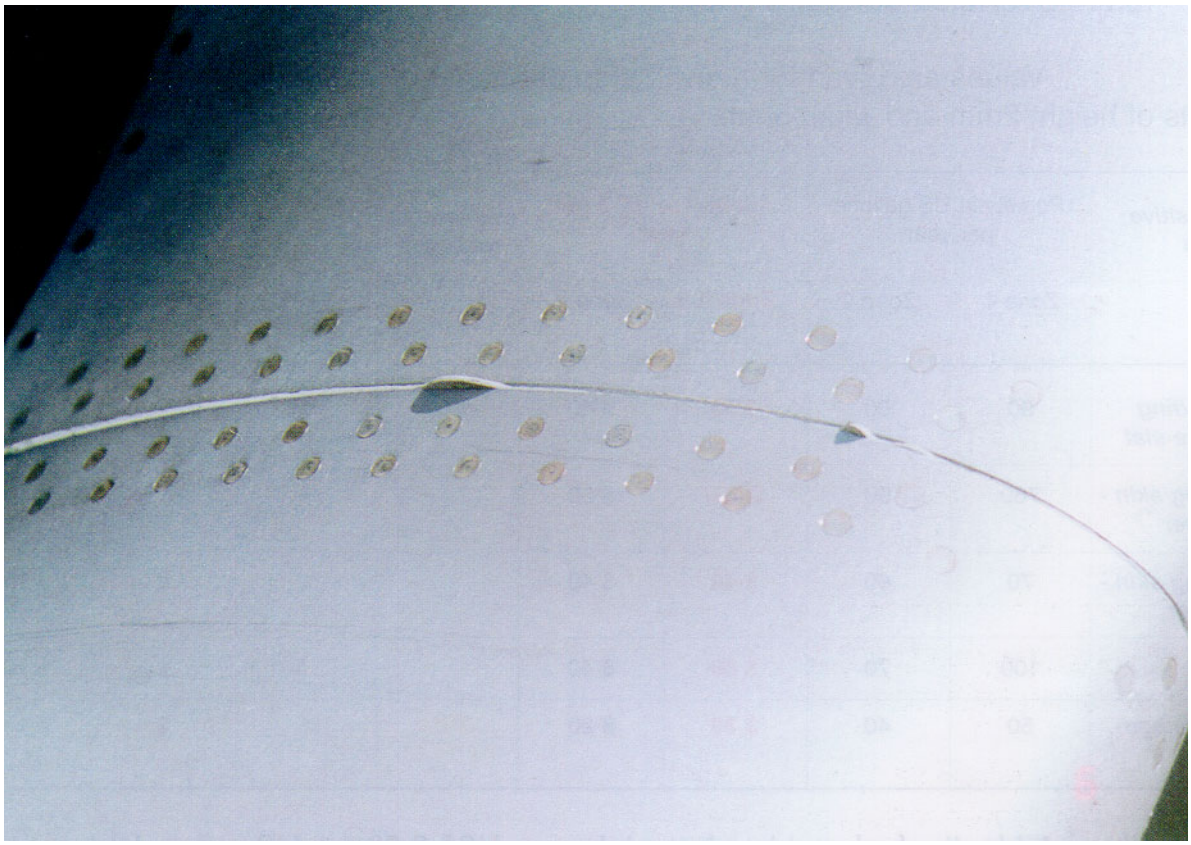
5.7.1 Overfilled butt joint gaps

Values are given for a given step per meter of sealant for overfilled butt joints of height 2mm and width 5mm.

Sensitive area	Penalty in US gallons per year		**Penalty in US $ per year**		Maintenance reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Leading edge slat	90	60	**$ 50**	$ 40		1	2	**$ 100**
Wing skin – upper	760	90	**$ 450**	$ 50		1	2	**$ 100**
Wing skin – lower	70	60	**$ 40**	$ 40		1	2	**$ 100**
Tail	100	70	**$ 60**	$ 40		1	2	**$ 100**
Fuselage	50	40	**$ 30**	$ 20	**SRM 51 76 11**	1	2	**$ 100**

In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Overfilled butt joint gap



5.7.2 External patches

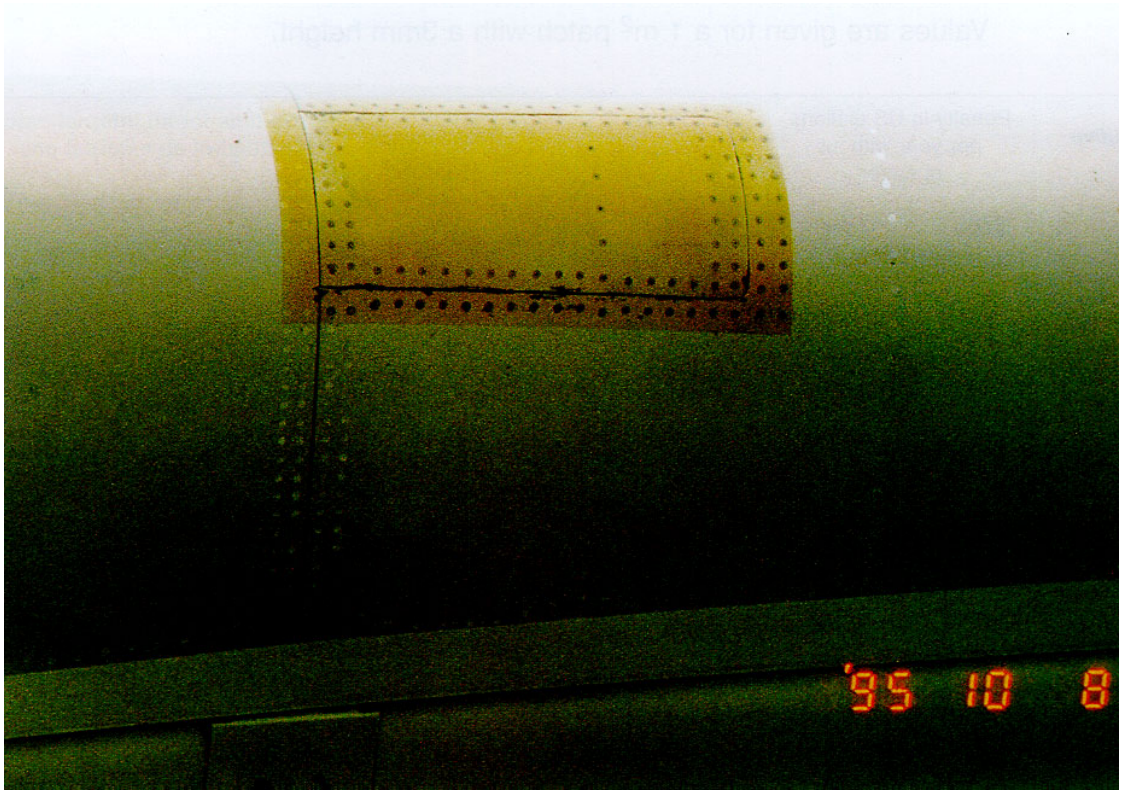
Values are given for a 1 m^2 patch with a 3mm height.

Sensitive area	Penalty in US gallons per year without chamber		**Penalty in US $ per year**		Maintenance reference	**Extra time for an Internal patch instead of an external one**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Wing skin – upper	1,826	1,050	**$ 1,100**	$ 630	**57 00 00**	2	60	**$ 3,000**
Wing skin – lower	320	320	**$ 190**	$ 190	**57 00 00**	2	60	**$ 3,000**
Tail	800	700	**$ 480**	$ 420	**55 00 00**	2	40	**$ 2,000**
Fuselage	410	280	**$ 240**	$ 170	**53 00 00**	2	40	**$ 2,000**

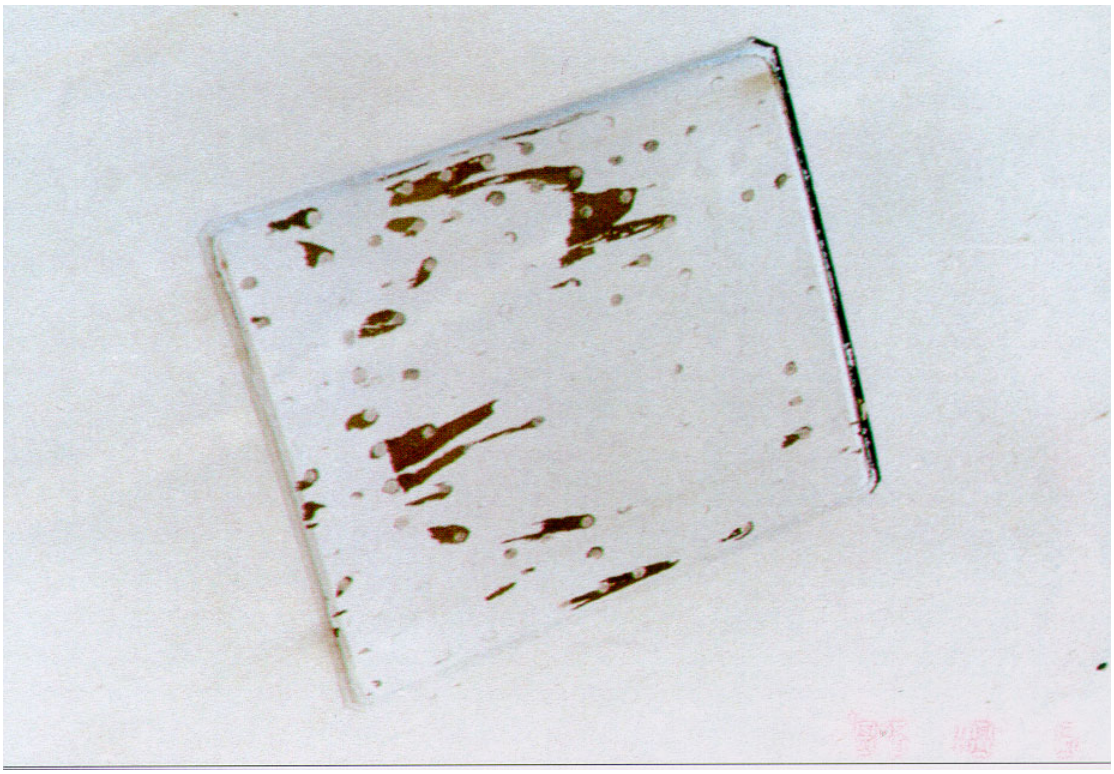
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

With a chamfer (slope 26°), multiply the above values by 0.27, except for wing skin – upper (multiply above values by 0.82).

Internal patch on the slat
leading edge



External patch



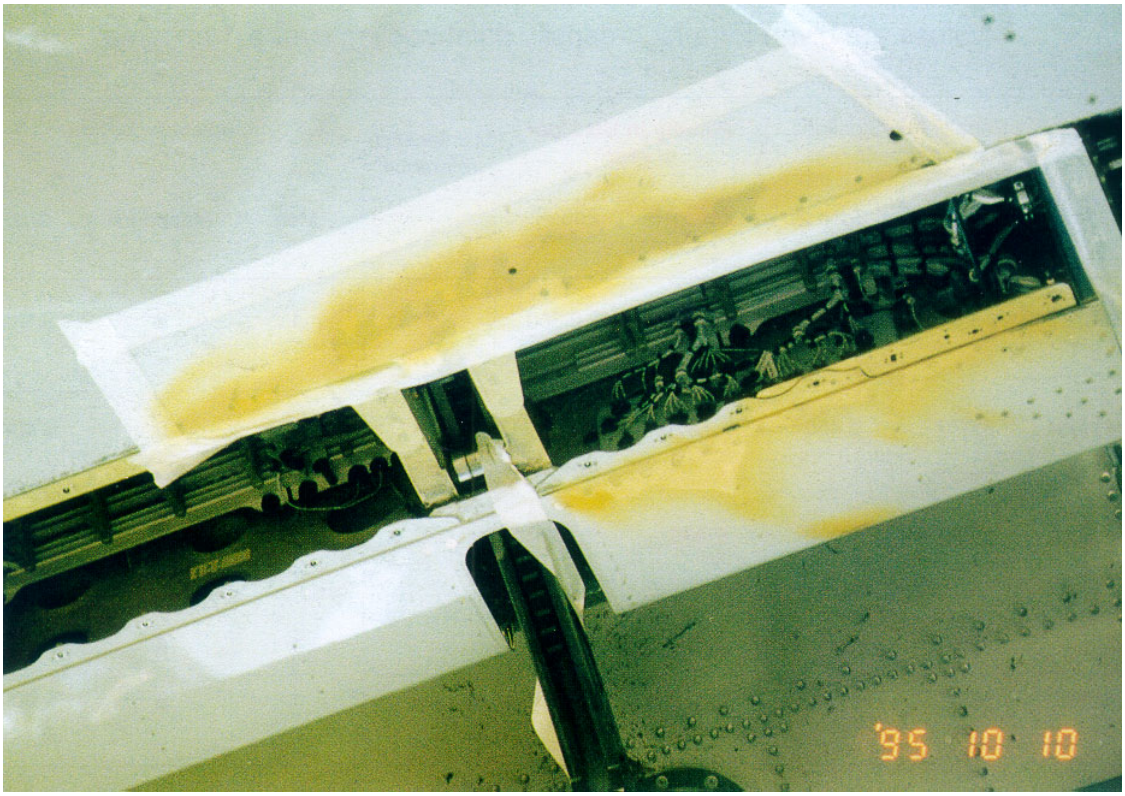
5.7.3 Paint peeling

Values are given for a high-density paint peeling over a 1 m^2 area.

Sensitive area	Penalty in US gallons per year		**Penalty in US $ per year**		Maintenance reference	**Corrective action**		
	Zone 1	Zone 2	**Zone 1**	Zone 2		Men	Manhours	**Cost**
Leading edge slat	6,380	3,930	**$ 3,830**	$ 2,350	**Repair of paint damage**	1	8	**$ 400**
Wing skin – upper	3,970	2,450	**$ 2,370**	$ 1,470	**AMM 51 75 12**	1	8	**$ 400**
Wing skin – lower	1,600	1,600	**$ 960**	$ 960	**SRM 51 75 12**	1	8	**$ 400**
Tail	1,360	1,010	**$ 820**	$ 600		1	8	**$ 400**
Fuselage	850	650	**$ 510**	$ 390		1	8	**$ 400**

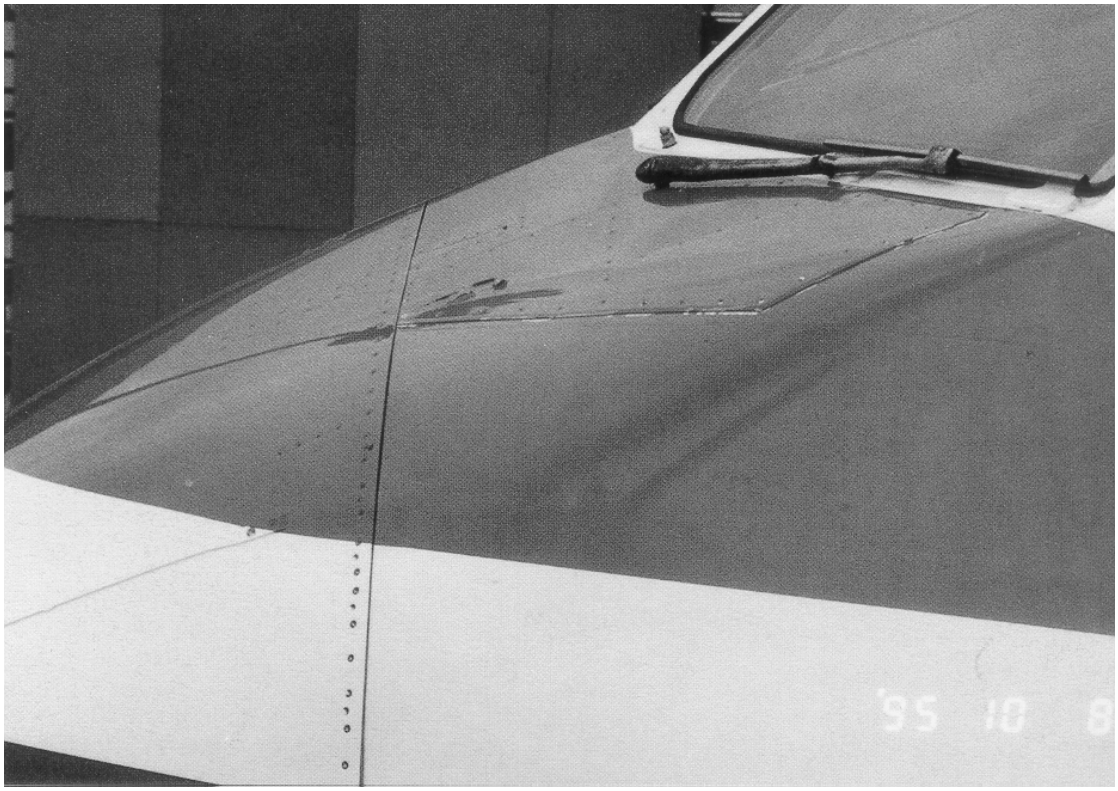
In the above table, the fuel cost has been taken as US$ 0.60 per US gallon; labour costs are assumed as US $ 50/h.

Paint peeling separation



Paint peeling

Paint peeling



Paint peeling on the slat
leading edge

6. CONCLUSION

6. CONCLUSION

The purpose of presenting the foregoing examples is simply to make operators and maintenance personnel more aware of drag-induced performance degradation on normal day-to-day operation. It has been shown that many, but not all, aerodynamic degradations can be easily detected and cost-effectively repaired. It ultimately becomes a matter of judgement for the airline to decide whether to rectify a fault or to ignore its effect.

Nevertheless, all maintenance and operations personnel should be aware of fuel penalties which may stem for misrigged control surfaces, defective seals and the lack of aircraft external cleanliness – especially at or near leading edges and forward sections of the aircraft.

Airbus Industrie is convinced that prevention is better than repair. Continuously monitoring aircraft aerodynamic efficiency, together with timely rectification of problems, is, without a doubt, the best approach to minimising unnecessary fuel consumption.