N92-30123

Ageing Airplane
Repair Assessment Program
for Airbus A300

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SUMMARY As a result of a commitment between the FAA and ATA the Airworthiness Assurance Task Force (AATF) steering committee requested the transport aircraft manufacturers to develop a program to assess the repairs on in-service aircraft since recent Supplemental Structural Inspection Programs (SSIP) had not been addressed to assessing repairs. The intent of the assessment program is to remove all existing ambiguities and to achieve a sufficient level of safety across the fleet by applying actual fatigue and damage tolerance criteria defined by FAR 25.571 to repaired structures.
A general three stage program has been developed with major aircraft manufacturers and airlines cooperation including area/component classification, repair categorization and inspection/removal requirement establishment which is the basis for model specific repair assessment programs.

This paper describes the current status of the repair categorization activities and includes all details about the methodologies developed for determination of the inspection program for the skin on pressurized fuselages. For inspection threshold determination two methods are defined based on fatigue life approach, i.e. a simplified and a detailed method. The detailed method considers 15 different parameters to assess the influences of material, geometry, size, location, aircraft usage and workmanship on the fatigue life of the repair and the original structure. For definition of the inspection intervals a general method is developed which applies to all concerned repairs. For this the initial flaw concept is used by considering 6 parameters and the detectable flaw sizes depending on proposed non destructive inspection methods. An alternative method is provided for small repairs allowing visual inspection with shorter intervals.

1. INTRODUCTION

As a direct result of several recent incidents on civil transport aircraft the FAA has launched several programs to assess aging transport aircraft, among others the assessment of existing repairs.

The Airbus repair assessment program is shortly described and comprehensive information is provided about the methodologies for assessment of repairs at Airbus A300 aircraft.

The main objective of these methodologies is the assessment of existing repairs on in-service aircraft, i.e. the determination of necessary inspection thresholds, and intervals and/or time of modification or replacement for the repair. The assessment of each repair includes static as well as fatigue and damage tolerance aspects.

2. REPAIR ASSESSMENT PROGRAM

2.1 Reason for Repair Assessment Program

Besides the recent incidents leading to a general concern, there are other technical and regulatory aspects for launching the assessment of repairs. Most of the repairs in service were designed for static and fail-safe criteria for aircraft designed prior to amendment 45 of FAR25. The SSID programs brought the aircraft designed pre-amendment 45 of FAR 25 to a status according to amendment 45, but the repairs were not addressed. Due to this aspect and under consideration of the age of the fleet the damage tolerance behaviour of the repairs has to be analyzed. In addition some repairs hide the primary structure to such an extent, that specific inspections may be required. Furthermore the interpretation of the earlier repair instructions may be difficult or the repair had not been performed in accordance with the instructions due to several reasons. At last the design principles and the justification methods of repairs have been evolved from entry into service of Airbus A300 till now, i.e. within approximately 20 years.

2.2 Objectives of Repair Assessment Program

The objectives of repair assessment program for the Airbus A300 fuselage, are clearly defined:

1. Demonstration of damage tolerance capability of repairs and surrounding structure
2. Assessment of repairs by the operators without complex analysis using guidance material supplied by Airbus Industrie
3. Establishment of appropriate actions for each repair, i.e. definition of inspection requirements and/or removal/modification limits.

2.3 Repair Categorization

The AATF task units have developed a general flow diagram, which shows the operator how to categorize the repairs and to apply the appropriate actions. Figure 1 shows a three-stage program including the application of the manufacturer's guidelines. Stage 1 assessment is followed by Stage 2 for principle structural element (PSE) areas which will be defined in the Structural Repair Manual (SRM). For non-PSE areas the normal maintenance program is considered to be sufficient. The Stage 2 assessment leads to one of the four categories with the following definitions:

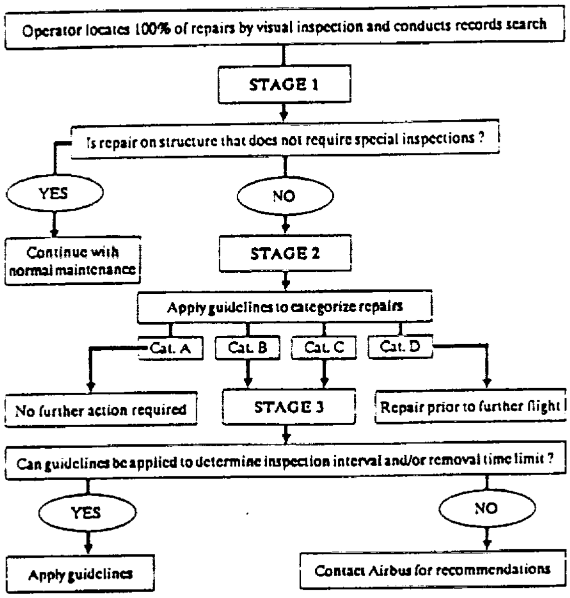


Figure 1: Repair assessment program

Category A
Meets the intent of the design certification basis of the airplane. Requires no special inspections other than normal maintenance.

Category B
Meets design certification basis of the airplane; however must be periodically inspected beyond normal maintenance requirements to ensure structural integrity.

Category C
Meets design certification requirements of the airplane; however, repair is clearly of a temporary nature. Structural integrity requires periodic inspections other than normal maintenance and repair must be replaced or upgraded to a category B or better at a certain time limit.

Category D
Does not meet design requirements and/or exhibits structural degradation. Must be upgraded to a category C or better by replacement or repair, before further flight.

The category A is achieved for repairs with sufficient static strength located in low stressed PSE areas which will be defined by Airbus Industrie. Category D applies mainly to repairs with marginal static strength or not designed according to the state of the art or being in a bad condition.

The Stage 3 assessment is applied for repairs categorized to B and C, i.e. establishment of inspection requirements and/or definition of replacement/modification time.

The manufacturer's guidelines for categorization in Stage 2 and the Stage 3 assessment which have been developed for the Airbus A300 are described in detail in the next chapters.

2.4 Evaluation Time Frame

Taking into account the age of the Airbus A300 fleet a time frame has been established for the operators activities, i.e. physical examination of the repairs, classification and assessment. The evaluation time frame, see figure 2, gives priority for implementation to more sensitive structures.

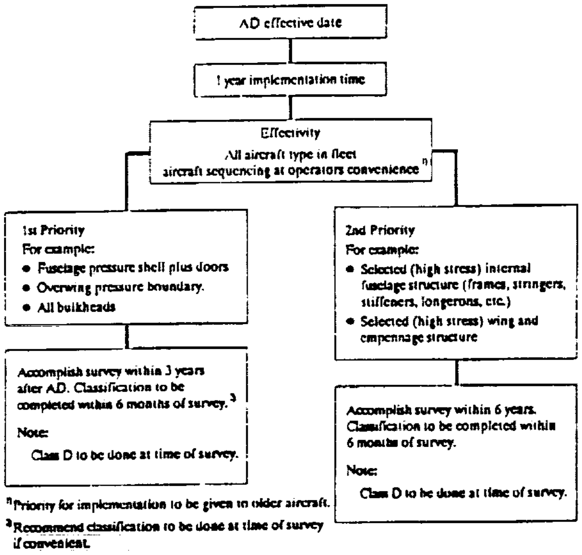


Figure 2: Evaluation time frame

3. PROCEDURE FOR REPAIR ANALYSIS

For the Airbus A300 the repair analysis consists of six major steps to categorize the repairs according to the categorization shown in chapter 2.3. For the categorization procedure, special repair questionnaires have been developed, e.g. for skin repairs, lap joint repairs etc. These repair questionnaires are based on a common understanding of major manufacturers and airlines. An example is given in Figure 3.

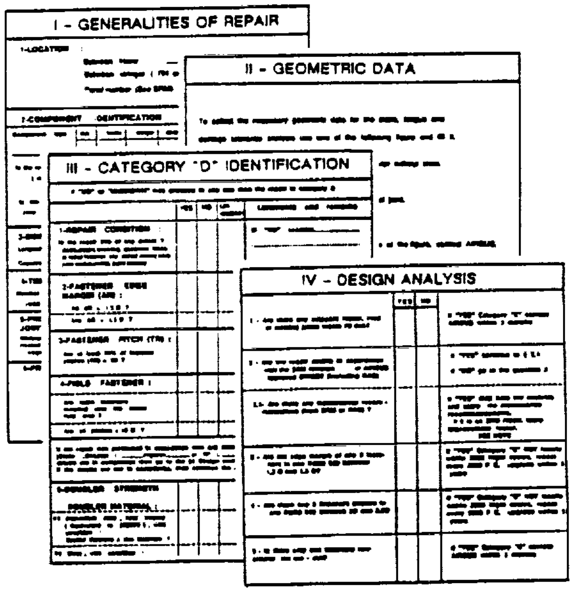


Figure 3: Repair categorization questionnaire

To minimize the activities of the airlines the procedure of the repair analysis is built up in such a way, that each repair will be checked first for categories D and C. This avoids unnecessary

determination of an inspection program for time limited repairs.
Figure 4 contains the procedure for repair analysis using the repair questionnaire.

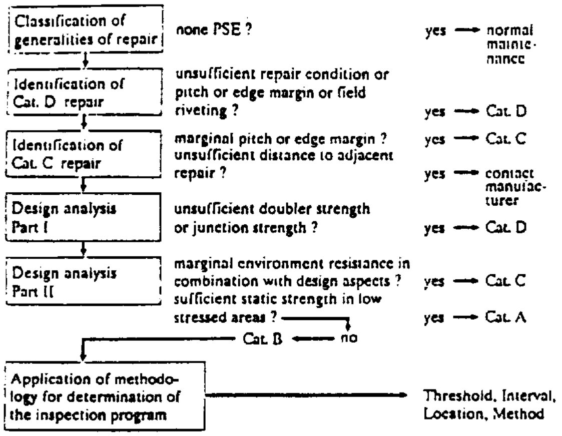


Figure 4: Procedure for repair analysis using the repair questionnaire

The first three steps of the procedure are easy to accomplish. Step 4, which is the design analysis Part I, includes a check of both, doubler strength and strength of fasteners. It is required that the doubler strength is greater than the strength of the skin and that sufficient fastener strength is available taking into account type of fastener, pitch, fastener diameter, skin/doubler thickness and location of repair.
Step 5, which is the design analysis Part II, includes a check of the environmental conditions in combination with design aspects. The accomplishment of a grading leads to categories A, B or C.
Step 6, to be performed for category B only, is the application of the methodologies for determination of the inspection program. These methodologies, which have to be applied to the majority of the repairs, are described in chapter 4.

4. METHODOLOGY FOR DETERMINATION OF INSPECTION REQUIREMENTS FOR SKIN REPAIRS

For repairs categorized as B, an inspection program has to be determined. The methodologies to be applied on Airbus A300 aircraft skin repairs are described here. Furthermore, methodologies have been either finalized or are under development for repairs of the following Airbus A300 structure:

- fuselage longitudinal and circumferential joints
- skin of vertical stabilizer (metallic)
- door skin
- door surrounding frames
- door surrounding panels

Figure 5 shows a principle sketch of a skin repair.
In principle, four fatigue sensitive locations exist, for which the inspection requirements have to be determined:

o longitudinal rivet row on doubler adjacent to cut-out
• longitudinal rivet row on skin at doubler run-out
Δ circumferential rivet row on doubler adjacent to cut-out
▲ circumferential rivet row on skin at doubler run-out

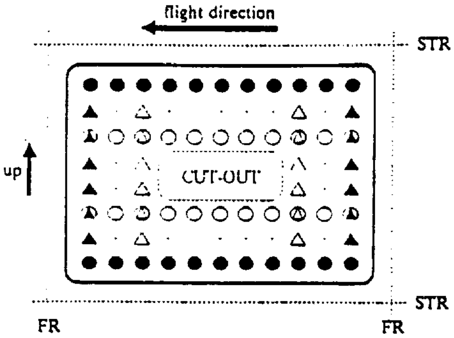


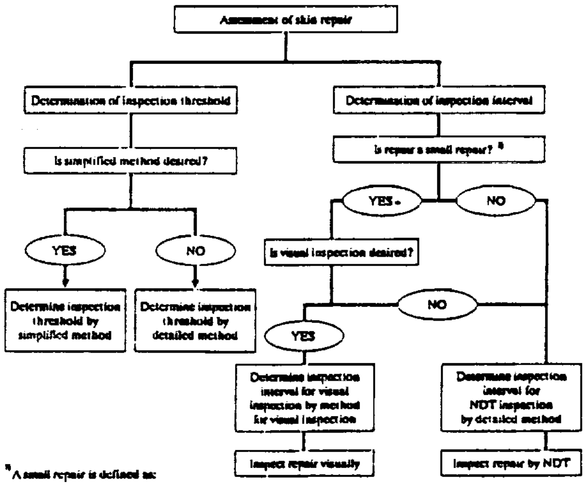
Figure 5: Principle sketch of skin repair

The inspection requirements to be determined are:

Threshold (TH) and Interval (I)

The determination of the inspection for the circumferential rivet rows is only required above the window line with one exception in the cockpit area.

For threshold determination two methods of different complexity have been developed according the airlines requests. The detailed method leads to the maximum allowable threshold in contrast to the so-called simplified method which is less time consuming. For interval definition in general a detailed method is to be applied resulting in maximum allowable intervals for NDT inspection. For small repairs an alternative method is provided allowing detailed visual inspections. An overview about the application of the methods is shown in Figure 6.



*A small repair is defined as:

Doubler length ≤ 200 mm for skin thickness ≤ 1.6 mm
≤ 250 mm for skin thickness 1.8 mm to 2.2 mm
≤ 300 mm for skin thickness ≤ 2.4 mm

Figure 6: Alternative Methods for Determination of Inspection Program

4.1 Determination of Inspection Threshold for Skin Repairs

4.1.1 Detailed method

The methodology is based on the following procedure:

A so-called basic threshold is given for a specific skin repair for an unlimited cut-out in the upper shell of the rear fuselage at a defined location. All data for this repair as geometry, aircraft utilization, materials, rivet types etc. are exactly defined.

The inspection threshold for a repair at another location of the aircraft and/or different geometry and/or different other parameters can be determined by the operator by multiplying the basic threshold with factors considering the influence of the different parameters. The factors are to be determined from diagrams or tables which are supplied in the guidelines. At last the time of embodiment of the repair is to be added to the calculated threshold to obtain the inspection threshold in number of flights for the specific aircraft under investigation.

The equation for calculation of the inspection threshold of skin repairs is given below:

$$TH = TH_{basic} * LO * SC * DT * EC * RD * RT * RC * PI * ME * RR * UT * CO * AC * SR * SM + TR$$

with
TH_{basic} : basic threshold
LO : location of repair
SC : size of cut-out - only for longitudinal rivet rows
DT : doubler thickness - only for doubler
EC : eccentricity
RD : rivet diameter
RT : rivet/bolt type
RC : former countersunk - only for skin
PI : rivet pitch
ME : edge margin - only for doubler
RR : number of rivet rows
UT : aircraft utilization - only for circumferential rivet rows
CO : countersunk depth
AC : countersunk depth/height
SR : distance of rivet rows
SM : distance of inner rivet rows - only for doubler
TR : time of embodiment of repair

The accuracy of the method is acceptable, considering, that all skin thicknesses are between 1.6 mm and 2.5 mm in the fatigue sensitive areas. Furthermore the maximum threshold is limited to the economic repair life plus time of embodiment of the repair.

The explanations given below are related to the longitudinal rivet rows only.

4.1.1.1 Basic threshold for skin repairs

The basic threshold in flights is given in Table I.

TABLE I

BASIC INSPECTION THRESHOLD FOR SKIN REPAIRS

Item	THbasic (flights)	
	circumferential rivet rows	longitudinal rivet rows
skin	35 000 (▲)	30 000 (●)
doubler	45 000 (△)	38 000 (○)

The determination of the basic threshold is based on coupon specimens tested under constant amplitude loading at different levels. The specimens are shown in Figure 7.

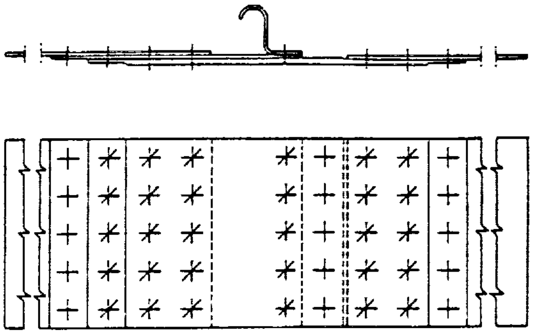


Figure 7: Specimens for coupon testing

The failure of the specimens occurred in both, skin and repair doubler, therefore the resulting SN-curve is valid for both locations. The applied aircraft spectrum for the longitudinal rivet rows is a one-step-spectrum due to internal pressure. The stress level used for calculation is based on analysis and considers in addition the results of former comparisons between coupon testing and full scale fatigue testing. Furthermore a scatter factor of 3 is used according to former agreement from French and German Airworthiness Authorities. The lower basic threshold for the skin compared with the doubler considers a countersunk in the skin to create a common basis for external doubler repairs and flush repairs.

4.1.1.2 Factors applied on basic threshold

The major factors are explained in the following:

* LO - location of repair

The factor LO, which considers the location of the installed repair, is based on the different stress levels in the fuselage. For the longitudinal rivet rows, which are loaded by internal pressure only, LO is determined using the hoop tension stress and the slope of the SN-curve used for the basic threshold determination. The location factors for the rear fuselage are shown in Figure 8.

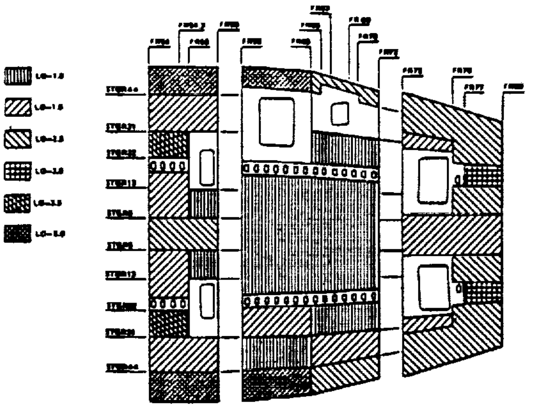


Figure 8: Location factors for longitudinal rivet rows of skin repairs in rear fuselage

* SC - size of cut-out

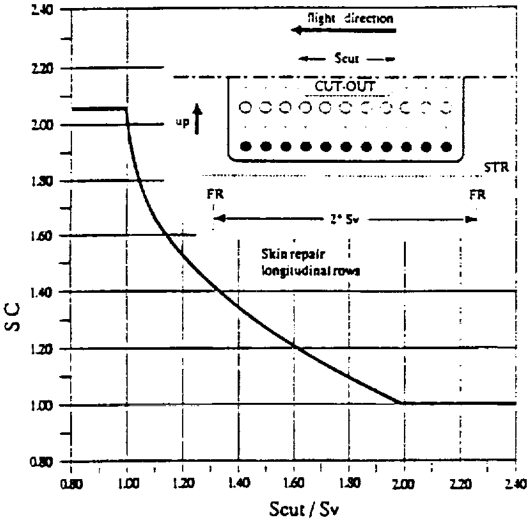


Figure 9: Influence of cut-out size

Figure 9 shows the effect of the cut-out size in relation to the length of a frame bay. This factor takes into account, that the load transfer is mainly a function of the cut-out size which is analyzed using Ref. /1/. The resulting stresses and the a.m. SN-curve are used to define the factor SC.

* DT - doubler thickness

The influence of the doubler thickness is shown in Figure 10. DT is determined considering that the variation of the doubler thickness is not fully effective due to bending effects. Internal investigations led to the conclusion to consider half of the thickness variation for lap splices with thicknesses similar to Airbus A300 fuselage skin. The variation of stress is then converted into fatigue life variation using the slope of the relevant SN-curve.

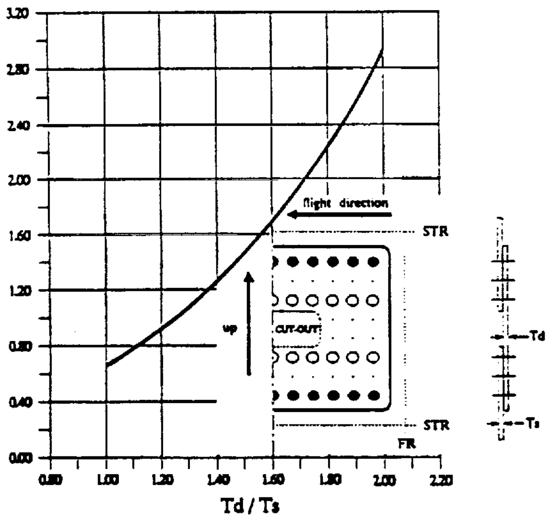


Figure 10: Influence of doubler thickness

* RD - rivet diameter

The influence of the rivet diameter in relation to skin or doubler thickness is based on test results issued in Ref. /2/ and shown in Figure 11.

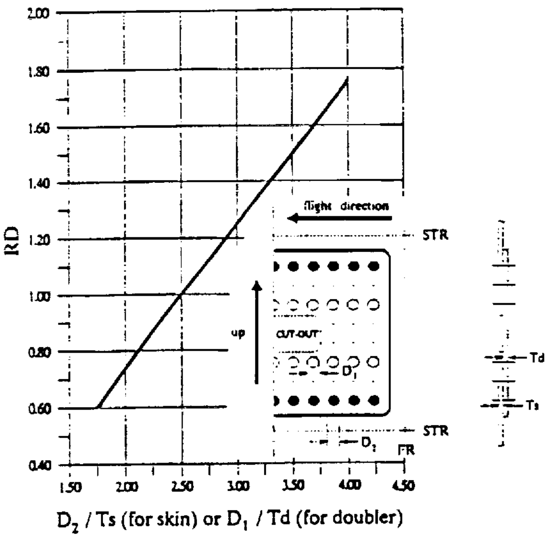


Figure 11: Influence of rivet diameter

* RT - rivet/bolt type

The factor RT considers the various conditions of the rivets/bolts as heat treatment, bolt fit, shape of rivet head and material. The results given in Table II are an extract from the future content of the repair assessment program and are obtained from several coupon test series, which have been performed during the design of the various Airbus types.

TABLE II

INFLUENCE OF RIVET/BOLT TYPE

Rivet type	RT	
	Manufactured head	Formed head or nut side
NAS 1097 DD	1.00 (c)	1.30 (p)
NAS 1097 D		
- heat treated	1.00 (c)	1.30 (p)
- non heat treated	0.50 (c)	0.65 (p)
Hi-Lok (Ti or Steel)		
- interference 1.0% D	1.30 (c)	1.69 (p)
- interference 0.3% D	1.10 (c)	1.43 (p)
- no interference	1.00 (c)	1.30 (p)

(c) ... countersunk head, (p) ... protruding head

Beside the major factors described above, ten additional factors have an influence on the fatigue life, i.e. on the inspection threshold of the repair. Most of these factors may be significant for repairs not in accordance with the recommendations defined in the SRM.

4.1.2 Simplified method

The so-called simplified method for determination of the threshold is based on several assumptions about the conditions of the repair, i.e. about the parameters influencing the threshold. These assumptions lead to certain values of the factors described in chapter 4.1.1, which are applied to the basic value TH_{Basic} (see chapter 4.1.1). The inspection threshold is determined by the following equations:

- unlimited cut-out in all areas and limited cut-out above window line:

$$TH = 12\,000 * PI + TR \quad \text{(flights)}$$

- limited cut-out below window line:

$$TH = 24\,000 * PI + TR \quad \text{(flights)}$$

A limited cut-out is less than half a frame bay in longitudinal direction. For PI and TR see chapter 4.1.1.

For application of the simplified method some limitations have to be considered. The major limitations are:

- external doubler only
- skin thickness: $Ts \geq 1.6mm$
- doubler thickness Td:
  - unlimited cut-out
    for $1.6mm \leq Ts \leq 2.0mm$: $Td = Ts+T$, $T \geq 0.2mm$
    for $Ts > 2.0mm$: $Td \geq Ts$
  - limited cut-out: $Td \geq Ts$
- solid fastener (no blind fastener)
- minimum three rivet rows

4.2 Determination of Inspection Interval for Skin Repairs

4.2.1 Detailed method for NDT inspection

The determination of the inspection interval is based on the same procedure as explained for the inspection threshold, i.e. a basic interval is to be multiplied by factors to consider all relevant deviations between the basic repair and the concerned repair. This method can be applied to all repairs independent on the size.

The equations and factors to be used are given below:

$$I = I_{Basic} * LOI * SCI * MAI * DTI * PII * UTI$$

with:

I_{Basic} : basic interval
LOI : location of repair
SCI : size of cut-out - only for longitudinal rivet rows
MAI : material
DTI : doubler thickness - only for doubler
PII : rivet pitch
UTI : aircraft utilization - only for circumferential rivet rows

The maximum interval is limited to 12 000 to 18 000 flights depending on the Airbus A300 derivatives.

The explanations given in the following are again related to the longitudinal rivet rows of external skin repairs.

4.2.1.1 Basic interval for skin repairs.

The basic interval in flights is given in Table III.

TABLE III

BASIC INSPECTION INTERVAL FOR SKIN REPAIRS

Item	IBasic (flights)			
	circumferential rivet rows		longitudinal rivet rows	
skin	4 500 (▲)	*1	6 000 (●)	*1
	5 000 (▲)	*2	7 000 (●)	*2
doubler	9 000 (△)	*3	12 000 (○)	*3

NDT methodology for external repairs:
*1 ultra-sonic from outside
*2 eddy-current high frequency from inside
*3 eddy-current high frequency from outside

The determination of the basic interval for the longitudinal rivet rows is based on the results of a multiple crack pattern evolution in a two-rivet row single shear joint of a large test article. This crack pattern is considered to be more realistic than assuming arbitrary crack pattern consisting of one 0.05 inch flaw at a center fastener hole and several 0.005 inch flaws at adjacent fastener holes. The inspection interval is calculated by application of a scatter factor of 2. Furthermore alternative inspection methods requiring different access have been considered. The detectable crack lengths are based on a detection probability of 95 percent and a confidence level of 90 percent.

4.2.1.2 Factors applied on basic interval

For the interval of the longitudinal rivet rows five factors are of special importance, i.e. LOI, SCI, MAI, DTI and PII. In principle the factors LOI, SCI, and DTI have a similar effect as the corresponding factors LO, SC and DT on the threshold as explained in chapter 4.1.

Details of the remaining two factors are explained below.

* MAI - material

In the majority of the areas, the skin and doubler material is 2024T3/T42 resulting in a material factor of 1.0. In exceptional areas the material 7075T6 is used which leads to an average material factor of 0.7 considering the increased crack growth in this material.

* PII - rivet pitch

Figure 12 shows the influence of the rivet pitch on the inspection interval. The factor PII is the result of a comparative crack propagation calculation showing increasing crack propagation periods for increased rivet pitches. This effect is in line with results given in Ref. /3/.

Additionally, Figure 12 shows the effect of the pitch on the threshold, which has a reverse effect as verified in many investigations.

For the circumferential rivet rows the factor UTI has to be applied to consider the concerned Airbus A300 derivative, i.e. B2, B4, C4 and F4, and the average airborne flight time. The factor UTI is significant for the following conditions: A300B4 derivative, rear fuselage and medium/long range utilization. For example a six hour flight leads to a reduction of the interval of 33 percent compared with a one hour flight of a B2 aircraft.

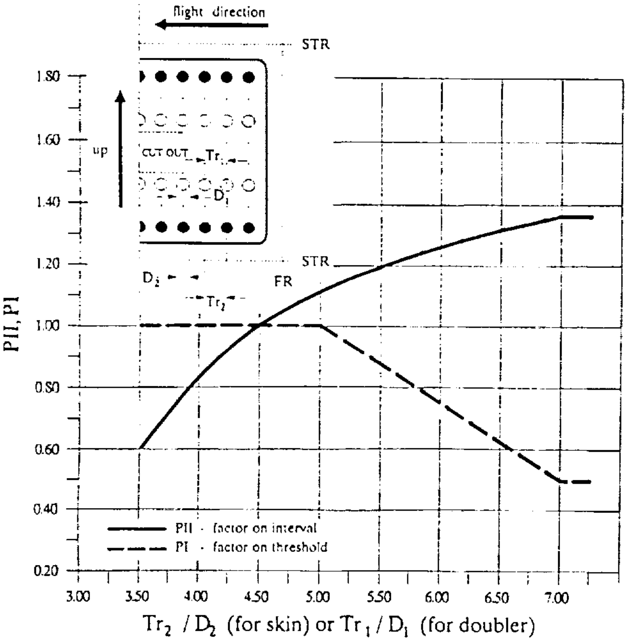


Figure 12: Influence of rivet pitch

4.2.2 Visual inspection of small skin repairs

For easily accessible areas of the fuselage, i.e. below the window line, an alternative method is provided which allows detailed visual inspections. This method is based on the assumption, that the skin in the doubler area or the doubler can completely crack without immediate impact on the safety. Assuming a detectable crack length of 25 mm at each side of the doubler the initial crack length for a crack propagation calculation is the doubler length plus 50 mm. Crack propagation calculations were performed for different skin thicknesses, i.e. for different stress levels. A scatter factor of 2 is applied on the crack propagation period between detectable and critical crack length, as done for the interval for NDT inspection as well.
To reach reasonable inspection intervals and to limit the possible crack length in the skin the visual inspection is limited to so-called small repairs. Small repairs are defined by the doubler length Sd depending on the skin thickness Ts as follows:

- for $Ts \leq 1.6mm$: $Sd \leq 200$ mm
- for $1.8mm \leq Ts \leq 2.2mm$: $Sd \leq 250$ mm
- for $Ts > 2.2mm$: $Sd \leq 300$ mm

Figure 13 shows the intervals for visual inspections depending on the doubler length and the skin thickness. The intervals are between approximately 300 flights for a 200 mm doubler on the 1.6 mm thick skin and approximately 12 000 flights for a 125 mm doubler on a 2.4 mm thick skin. If the interval is not convenient considering the airline's maintenance schedule the interval for NDT inspection is to be determined acc. chapter 4.1.1.

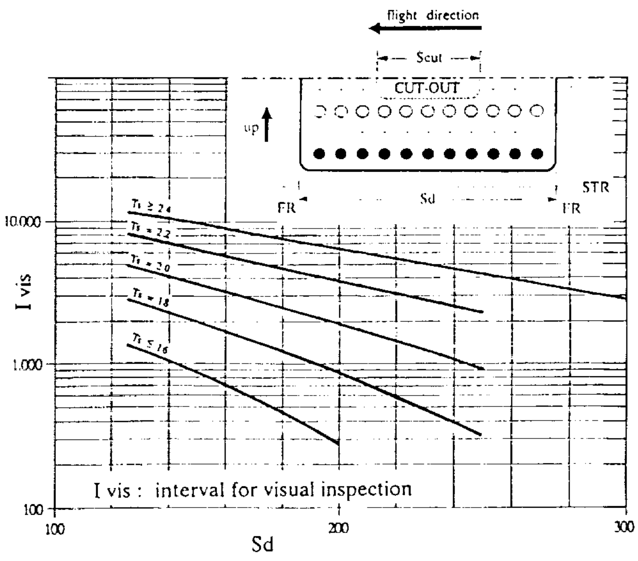


Figure 13: Intervals for visual inspection of small repairs

5. CONCLUSION

The developed repair assessment program is considered to be an adequate response to the requirements defined by the AATF steering committee. The main subject of the repair assessment program is the methodologies for determination of the inspection program. A draft of the detailed methodology for assessing skin repairs has been presented to the airworthiness authorities, members of the AATF and Airbus A300 operators. The method, which was tailored to the airlines' requirements regarding limitation of work load and complexity, has been accepted.

The presented methodologies have significant advantages for the airlines, since they apply to nearly all fuselage skin repairs, even to those not in accordance with the manufacturer's instructions. The detailed methodology allows detailed evaluation with simple calculations and provides maximum allowable thresholds and intervals. Furthermore the methodology contains guidance material for design of repairs with high inspection thresholds and long inspection intervals. After finalization of the methodologies for other fuselage structural elements prone to repairs (early 1992) and the repair assessment document, the airlines will be in a position to assess more than 90 percent of the existing fuselage repairs without support of Airbus Industrie.

6. REFERENCES

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