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A MANUFACTURER'S APPROACH TO ENSURE LONG TERM STRUCTURAL INTEGRITY

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SUMMARY

In the present paper we are as a manufacturer of airliners, certified according to the FAR 25 regulations, describing what considerations in terms of design, sizing, verification, maintenance, etc. that are essential to ensure long term structural integrity.

In the first part we are describing the main features of the design concepts of Saab 340 and Saab 2000 aircraft with respect to structural integrity and high reliability. Secondly we are describing the approach we have adopted at Saab Aircraft to ensure structural integrity and high reliability of Saab Aircraft products. We are describing the concepts of global and local loads and sequences, the fatigue and damage tolerance sizing and its verification. We are also describing the quality assurance in production and the structural maintenance programme according to the MSG-3. Structural repair and feedback from operators are also covered.

1. INTRODUCTION

When Saab Aircraft 10 years ago entered into the commercial aircraft business it was from a background as a developer and manufacturer of military fighter aircraft. Saab Aircraft has for more than 50 years been the main contractor and has delivered fighter aircraft to the Swedish Airforce. With this long tradition we realized the importance of long term structural integrity and high reliability built into the product.

In order to reach high reliability throughout the service life of an aircraft a well developed and solid cooperation between the manufacturer, customers and authorities is required. It is also important that the manufacturer has a thorough and systematic approach covering all the stages from early design to the customers use of the aircraft with feedback to the manufacturer including means of modifications and repair depending on field experiences.

Long term high structural reliability is built up from a good and sound design, high quality manufacturing and a professional use of the aircraft including monitoring of the usage and feedback to the manufacturer.

The base for structural integrity and high reliability is set already at the design stage by sound engineering design concepts based upon requirements of integrity, simplicity and maintainability. Important for high reliability is internal load distribution, fatigue resistant materials, high quality joint technologies and verified good corrosion protection systems. Very important and basic to all design is knowledge about conditions under which the aircraft are going to be used - load levels and sequences, environmental conditions etc.

It is thus, for the developer, important to have high quality engineering design and sizing methods. Important in such a concept are methods to obtain internal loads distribution based upon the knowledge of global load levels and sequences, methods for sizing to static, fatigue and damage tolerance criteria. Access to design allowables for the different materials under actual environmental conditions is also important.

Included in this concept are also the verification procedures where the design is verified by testing at different levels of complexity from simple coupon tests to fatigue and damage tolerance testing of a complete airframe. Verification of loads on the aircraft is made by flight testing and feedback from the usage of the aircraft. Internal loads are verified also by testing.

Quality assurance in production by qualification of processes and equipment and control of processes and details is important to secure the final product quality. Quality control in production by non-destructive testing and inspection methods is important, especially when using new advanced technologies like composite designs, bonding technology etc.

To secure high quality throughout the service life of the aircraft it is necessary to have a well developed structural maintenance program. This shall include analysis of the structure and classify structural significant items and fatigue, environmental and accidental damage analysis. From this analysis a structural inspection programme is developed.

In order for the customer to be able to maintain structural integrity and reliability it is important to develop a structural repair manual including descriptive information and specific instructions, material identification, allowable damage criteria and repair design solutions together with procedures and processes. This manual should be continuously updated with new repair schemes. In addition the customer should be supported by a product support team at the developer for repair and special damages that are not covered by the repair manual.

Feedback from the customers on how the aircraft are used and feedback of damage information to the developer is of utmost importance for being able to maintain structural reliability and also to improve future product quality by influencing future design solutions by experiences from the field.

Last but not least it is important that the operator develop and maintain high quality and skilled personnel that operate and maintain the aircraft according to defined procedures.

2. DESIGN CONCEPT OF SAAB 340 AND SAAB 2000

Aircraft structure should be designed for a low risk of fatigue crack initiation throughout the design life. However it can not be guaranteed that fatigue cracking will not occur in at least some aircraft of the fleet. Aircraft structure may also be cracked due to corrosion, incorrect maintenance or impact damages from accidents such as turbine disk desintegration or propeller break-up.

This means that besides an overall high fatigue quality and a good corrosion prevention system, the structure must be designed also with damage tolerance capabilities. Such a damage tolerant structure should maintain sufficient residual strength until any cracks or damages are detected during scheduled inspections.

2.1 The structural design concept

Saab´s on-going programmes dedicated to research and development of new structural concepts, together with experience gained on military and other civil projects, provide a firm base of advanced technology on which the Saab 340 and Saab 2000 structural design are built. The structural design is based on three main objectives:

o Integrity
o Simplicity
o Maintainability

The Saab 340/2000 makes extensive use of the PABST bonding technology in the fuselage and the wings, and of advanced materials on control surfaces. Structural simplicity is greatly enhanced by the use of bonding in more than 40% of the structure.

2.1.1 The fuselage

The fuselage structure consists of three major assemblies:

o The forward section (with cockpit)
o The centre section (cabin)
o The rear section including cargo compartment

The forward and rear skin are partly a conventional design which makes use of chemical milling techniques and partly bonded design.

For Saab 340 and Saab 2000 the centre cabin section is built up of top, bottom and two side panels. These single-piece panels consist of an outer skin to which the doublers and stringers are bonded. Additional for Saab 2000 is that the top and side panels are spliced fore and aft of the centre section due to its length. Plug type doors are standard throughout the pressurized cabin.

2.1.2 The wing

The wing is an assembly of left- and right-hand wing panels spliced at the aircraft centre line. As this is the only splice for these major components, good weight efficiency and high durability are achieved. The wing box structure is of conventional design built on two spars, with the volume between the spars over a certain wingspan used for an integral fuel tank with access doors in the upper panel. The upper and lower wing panels are bonded assemblies. Trailing edge panels are made of composite materials.

2.1.3 The empennage and control surfaces

Sandwich panels with metal honeycomb are utilized in the construction of the fin and horisontal stabilizer. Bonded assemblies of honeycomb are used in order to reduce the weight and the number of parts. Furthermore, these structural techniques provide a smooth surface finish and low drag for further gains in performance efficiency.

2.2 The use of structural bonding

Saab Aircraft started to use adhesive bonding on the Saab 29 fighter aircraft "The Flying Barrel" in production in 1953 and has applied this technique successfully over time to an increased extent in primary structures of the aircraft Saab 32 "Lansen", Saab 35 "Draken", Saab 105, Saab 37 "Viggen" and Saab JAS 39 "Gripen".

Rationalization for metal to metal bonding are:

- Weight optimal
- Damage tolerant structure
- Better aerodynamic performance due to smoother surface
- Increased stiffness in thin gauges design
- Reduced needs for using mechanical fastener holes which are potential candidates for both initiation of fatigue cracks and corrosion
- Inherent corrosion protection in areas with doublers

Saab has developed the bonding technology to bond large complicated panels with skin, doublers, stringers, reinforcement frames and window frames in one or more bonding operations. Metal to metal bonding is sometimes used even for double curvature panels. Figure 1 shows a metal to metal bonded structure.

2.3 The corrosion protection system

Corrosion protection of the aircraft is among the most comprehensive in industry. A fully automated facility ensures the anodization of the different parts before assembly. This is followed by applying a primer which ensures protection against the various forms of corrosion over a long period. The corrosion protection scheme is shown in figure 2.

2.3.1 Painted exterior surfaces

Our approach to make inspection easier of the exterior is to have a semi-strippable paint scheme. This means that we have chosen a system easy strippable down to a transparent organic film. The remaining coatings consist of phosphoric acid anodizing and a transparent bonding primer. There are a number of advantages with this scheme over a conventional one:

- No grinding operation is required
- A relatively mild non-phenolic stripper which does not degrade the adhesively bonded joints can be used.
- There is no need for acid deoxidizing and swabanodizing of the stripped aircraft prior to repainting. Referred treatments may cause corrosion if residues are left in crevices. Good adhesion is secured by the bonding primer
- The adhesion between the bonding primer and the phosphoric acid anodize is unsurpassed. It has been found that this pretreatment resists filiform corrosion better than any other treatments we have tested. Filiform corrosion occurs more readily on clad than on bare materials overcoated with polyurethane top coats. It has also been found that phosphoric acid anodize plus bonding primer gives better resistance against exfoliation corrosion around fastener heads than chromic acid anodizing does.

Hydraulic fluids are known to affect paint coatings. The hydraulic fluid based on phosphate ester called Skydrol is found to be the most effective paint stripper. A strippable paint scheme containing a wash primer does not resist Skydrol. The removal of paint schemes that resist Skydrol requires use of corrosive phenolic strippers, severe grinding operations and chemical brightening with an obvious risk for structural damage. Many airliners therefore reapply a strippable system on all exterior areas except for those known to be heavily contaminated by the hydraulic fluid. We have chosen to use a strippable paint system from the very beginning.

2.3.2 Protection of interior areas

There are a lot of crevices and fasteners in the interior area of an aircraft with a potential risk for corrosion. Our philosophy is to apply paint in the detail stage which also is desirable in securing good adhesion. During assembly, parts are fay and fillet sealed to standard praxis. After assembly of the whole aircraft but before installation of insulating blankets we apply a water displacing protective oil which effectively penetrates any crevice left. Several visits and interviews with airliners have indicated that such a protective oil is highly desirable during manufacturing of a new aircraft. It is now also required in IATA doc. 2637, issue 2.

2.3.3 Special design considerations

The design concepts are a determining factor for corrosion resistance. In order to get adequate protection, corners and edges on metals used in exterior locations or in areas exposed to a corrosive environment are broken prior to protection. This procedure is also applied to metals prior to shot peening. Items made of forging and plate product forms are protected as follows:

- Cold working by shot peening or blasting
- Polishing of critical radii
- Chromic acid anodizing using a process with good reproducability and painting.

Considerable condensation takes place expecially inside the outer skin and in the ventilation system therefore provisions are made for adequately sized drainage paths. Contact between porous materials and metals is avoided. Thus, it is important that e.g. insulating blankets are not installed tight and wrapped around stringers or in contact with the skin.

All faying surfaces in exterior locations and corrosion prone areas are sealed unless not adhesively bonded. Special consideration is also taken for interfaces between dissimilar materials.

The use of magnesium alloys in aircraft design needs special care. We have some twenty-five parts of a cast alloy designated ZE 41A. These parts are protected by surface sealing with a stoved epoxy resin prior to painting and are not used in areas exposed for an aggressive environment. Whenever possible, this resin is applied also to tolerance surfaces in order to avoid direct metal-to-metal contact. The magnesium castings are also protected against galvanic corrosion by use of wet assembly practice, aluminium washers and sacrificial coatings on dissimilar metals.

Carbon fibre composite material also possesses potential risks for galvanic effects especially in fastener installations. This is restrained by use of fasteners of titanium, monel or corrosion resistant steels.

In areas where galvanic corrosion may occur attention should be paid to the fact that it is better to arrange for drainage from the less noble metal to the more noble one than reverse and that the anode area should be large relative to the cathode area.

In highly corrosive areas such as beneath the lavatory, plastic materials, corrosion resistant steel or titanium are used and the area is enclosed from other structures. Areas highly susceptible to corrosion are easily accessible to permit cleaning and inspection.

For metal sandwich structure it is important to restrict transportation of humidity into and within the panel. Square-edge designed panels with a non-perforated core type and with all edges and holes adequately sealed is our solution.

Additions to the fuel in order to suppress fungi growth in aircraft operating in tropic countries has been considered insufficient as a single means of avoiding corrosion. The integral fuel tanks are therefore protected by a fungi resistant coating per MIL-C-27725.

3. LOADS ANALYSIS

3.1 External loads analysis

The external loads on the aircraft are analysed for all conditions specified in FAR/JAR regulations. In addition a number of states that occur during final assembly, jacking up during overhaul etc. are specified.

Determining the external loads requires analysis of e.g. structural dynamic response to specified extreme manouvres in flight, aerodynamic pressure distributions at different speeds, angles of attack etc. and gust loads, cabin pressurization, landing impact, taxiing, braking, turning on runway, etc.

Several different payload distributions are considered to find extreme loads for each state.

A large number of fail-safe conditions e.g. failure of certain structural components, failure of power assist devices, sudden engine stoppage, loss of propeller blade, etc. are also analysed for each state.

The load analysis makes use of techniques like the Finite Element (FE) method to predict dynamic transient response e.g. landing, Computational Fluid Dynamics (CFD) for prediction of aerodynamic pressure fields and 6 degree of freedom flight mechanics model with control system logics to predict in-flight manouvres. Numerical predictions are supported by wind-tunnel tests of models and finally verified during tests of complete aircraft.

3.2 Mission analysis

The complete definition of external loads also includes the definition of the load sequence. The usage of the aircraft throughout its design life is defined in a hierarchical way.

Basic information used includes the definition of the expected flight plan which involves climb, cruise, descent, flight times, operational speeds and altitudes, and the approximate time to be spent in each of the operating regimes. Operations for crew training and other pertinent factors, such as the dynamic stress characteristics of the flexible structure excited by turbulence are also considered. For pressure cabins, the loading spectrum include the repeated application of the normal operating differential pressure, and the superimposed effects of flight loads and external aerodynamic pressures.

The definition and handling of this sequence of load cases are described in section 4.

3.3 Internal loads analysis

The internal loads distribution in the structure is then obtained by solving the finite element model of the complete aircraft for all the defined unit load cases.

The present status of the basic loads analysis process is schematically shown in figure 3. Not shown in this scheme is the feedback from analysis to design and the verification process consisting of component tests, ground and flight tests.

4. FATIGUE AND DAMAGE TOLERANCE SIZING AND VERIFICATION

4.1 The sizing and verification concept

The design criteria for service life and damage tolerance requirements are met during the development phase through a fatigue and fracture mechanics concept based on what we refer to as the Global Spectrum Approach. This concept which is also a part of a global concept which involves applied regulations, feedback from structural and flight testing and follow-up of service experiences, etc. (figure 4). The method is computerized.

4.2 The computer aided system

The computerized system is handled by any stress engineer involved in a project and is used for both sizing and test planning work. A prerequisite for such fatigue and crack growth work is access to local load spectra or load sequences for any part of the structure. The information needed for this purpose are obtainable in each aircraft's two project central databases; these contain:

o The design loading of the aircraft, defined as a sequence of instantaneus load cases defined for the complete aircraft.

o Solved unit load cases for the finite element model of the complete airframe.

The system is in full production in both the military Saab JAS39 Gripen and the civil Saab 2000 aircraft programmes. Work is also going on to implement the whole system into a workstation based CAE system which involves graphical interfaces and transparent data communication links.

4.3 The loads spectrum handling procedure

4.3.1 Global sequence

The design loading of the aircraft is defined as a sequence of instantaneus load cases defined for the complete aircraft and available in the global sequence.

The efficiency of the system to handle and process load cases is based on the hierarchic structure of information in the global sequence (figure 5). Three levels for load case definition and three levels for the composition of the load case sequence are available.

Balanced load cases are obtained from linear combinations of solved unit load cases for the finite element model of the complete airframe. The current global sequence for the Saab 2000 aircraft contains 7824 unique load cases which are composed from 224 solved unit cases. Every unique load case is also assigned a code number. These code numbers are used for identification and are particulary important for the preparation of the structural testing.

On the lowest level for sequence definition, parts of a mission are defined. Load case sequences for ground conditions consisting of turns, bumps, breaking, towing, etc., manouvre and gust conditions for different configurations of the aircraft and landing conditions are defined as subsequences. Having this bank of sub-sequences, a number of complete missions can be defined as sequences of these sub-sequences. At the top level, the mix of missions are defined. It is not necessary to define a unique sequence for the whole service life. A repetition sequence representing approximately 5 percent of the total service life is sufficient. For Saab 2000 a unique sequence of 3000 missions is defined. For the whole design service life of 75,000 flights the global sequence consists of more than 285 million states.

4.3.2 Local spectrum

Local sequences and spectra for any calculated quantity for any location in the finite element model can momentarily be created by the stress engineer through the use of the system. For complex situations the system has features to facilitate a number of operations on the finite element results. Loads, moments, stresses, displacements, etc. can be factorized and superimposed and principal stresses and effective stresses can be derived.

When testing is planned or when cycle-by-cycle crack growth prediction shall be made, it is sometimes advisable to omit certain small cycles which from a fatigue viewpoint have no practical meaning. Interactive facilities to remove those insignificant states are available. Rules and guidelines for choice of truncation levels are based on spectrum test results.

As an example, a finite element substructure representing a part of a wing attachment frame, skin and window for Saab 2000 is shown in figure 6. A local stress sequence for the marked portion of the inner flange of the frame is obtained. Figure 7 shows this local sequence after an omission operation. The omission technique adopted works also when more than one load sequence is considered through a lowest common denominator scheme.

For very long irregular sequences like this the rain-flow counting algorithm that in a relevant way combines states into cycles is available. The counting is performed on the subsequence level with intermediate states treated afterwards and has been proven to be very computer time efficient. The distribution of counted rain-flow ranges for the above described reduced sequence and the original sequence are shown in figure 8. The rain-flow matrix of associated peaks and troughs as well as the local stress sequence are linked to the fatigue and fracture mechanics processes of the system.

4.4 The fatigue sizing procedure

The landing gear and their attachments are certified as safe-life structure and certification is based on fatigue testing. To minimize the risk of early failures in the tests and associated burden of modifications, thorough fatigue analyses are made.

Since all other structures are certified as damage tolerant, fatigue analysis is not a certification requirement. However, despite this fatigue, sizings are made for the following reasons:

- To set maximum allowable stress levels, in order to reach a low risk for fatigue cracking throughout the design service life.
- As one way to determine where, in a principal structural element, the assumed initial flaw for the damage tolerance evaluation shall be placed.
- In order to avoid multiple site cracking within the service life. Areas particularly prone to this phenomena are e.g. long splices, lower wing panel at ribs and back-to-back fittings.

The system process used for this purpose is based on a cumulative fatigue calculation method of a "Relative Miner" type. This means that the allowable damage sums are based on spectrum test results and depend on the type of structural item and type of loading. Several testing based computer aided procedures for adjustments in order to account for various deviating conditions in applied cases, e.g. size effect, surface roughness, surface treatment etc., are available.

In the early phase of design, when the configuration is still open to changes, it is of great importance and generally advisible to study the effect on critical damage sum from a change in stress level and configuration. Several graphical aids for this purpose are available (figure 9).

4.5 The damage tolerance sizing procedure

Damage tolerance means that the structure, at any time during the operational life shall maintain the required residual strength with an in-service detectable damage present, while subjected to the expected typical loading spectrum, until the damage is detected.

In the design and sizing of the structure it is therefore important not only to generate damage growth and residual strength data but also to consider the inspectability of the structure in-service.

To ensure residual strength in case of failure in an adhesively bonded joint some general and specific requirements exist. The bonded structure shall maintain the residual strength with any reasonably expected damage of a size that is likely to be detected by the in-service inspection program.

The principal structural elements and the damage critical areas where damages are simulated are identified accounting for the following factors:

- o Review of static analyses to locate areas of maximum stress and low margin of safety.
- o Select locations which by fatigue analysis are determined to be prone to fatigue.
- o Select locations where the crack path is short.
- o Select locations in an element where the stresses in the adjacent structure would be the maximum with the damage present.
- o Select locations where damage detection is difficult.
- o Select locations which, based on test or service experience on similar designs, are prone to fatigue damage.

For each critical damage location the most critical initial flaw is normally determined considering:

- o The initial flaw which will produce growth to a critical damage in the shortest time.

Considerations are also given to:

- o Initial flaws which will give the largest extent of damage before detection is possible.
- o Initial flaws which will lead to complete failure of one element in the shortest time.

Multiple or secondary initial flaws are assumed where the design is such that multiple site damages can be expected to occur due to fatigue.

The size and shape of the primary initial flaws are selected to cover manufacturing defects of what is generally known as a "rouge flawed aircraft". The secondary initial flaws are smaller since they are supposed to be caused by fatigue and subsequently in reality not existing at all on "day one" in the service life of the aircraft.

It should be pointed out that these initial flaws are not normally used to establish the inspection repeat intervals. The reason for introducing the primary flaw is to get a starting point for the crack growth prediction which accounts for manufacturing defects. The secondary flaw is used to determine the size of the damage for continuing crack growth.

The damage tolerance analyses are handled by fracture mechanics methods. The system process CAFE (Computer Aided Fracture Engineering) is doing this work and is linked to databases containing materials data and stress intensity factor solutions and has a broad range of methods and techniques to build and solve fracture mechanics models.

The principal result from the fracture mechanic analysis is a crack growth curve beginning from the assumed initial flaw size and ending at the critical crack size. This curve, figure 10, is used in the Maintenance Steering Group (MSG-3) procedure to establish at which time the normal in-service inspection programme for fatigue damages is initiated and the inspection repeat interval. The safety factors used to obtain the safe periods and intervals varies depending on the design.

4.6 Structural test verification

The fatigue and damage tolerance sizing create the necessary conditions for high structural integrity. This integrity need also to be demonstrated in testing according to the sizing approach shown in figure 4. The tests are made in order to:

- Verify freedom from premature fatigue cracks in primary load paths.
- Identify any premature fatigue cracks in the structure.
- Generate crack growth and residual strength information for artificial defects to correlate analytical predictions.
- Verify calculated inspection periods for fail-safe structure in the fail-safe mode.
- Determine inspection threshold and inspection repeat interval for naturally developed cracks.
- Verify fatigue life for safe-life structure.
- Verify freedom from multiple site damages where applicable.

The load spectrum handling process of the system takes here a principal part since it contains a large number of facilities which are necessary in the test preparation work task.

Besides the testing for obtaining data for predictions, e.g. fatigue curves for materials, lugs, joints, fastener systems and crack growth rates and fracture toughness etc, three main levels of testing are identified.

Detail testing is mainly performed early in the sizing work. It is used to verify detail design of vital structural members and to qualify the application of prediction methods to typical structural configurations.

Major component testing is done for early fatigue and damage tolerance verification. The key point in these tests is that a critical part is tested while properly installed in its nearest boundary structure. This type of testing will verify the structural integrity and the prediction of internal loads.

The final verification of the fatigue and damage tolerance performance is made with a complete airframe tested for several service lives. This test will spot fatigue critical areas and demonstrate the stable growth of those natural cracks that may initiate and of any artificially made cracks. The Saab 340 full-scale fatigue test has now exceeded 150,000 simulated flights. This test will continue to 180,000 flights before artificial cracks, of sizes which are in-service inspectable, are installed.

Examples of major fatigue and damage tolerance tests for Saab 2000 are given in figure 11.

5. QUALITY ASSURANCE IN PRODUCTION

The quality assurance of a product like a commercial aircraft is of utmost importance. The quality assurance task permeates all sub-moments in development and production. From a production point-of-view, the produced items must comply with the demands used in the design and sizing.

Flow diagrams for all work-shops are established and each sub-moment in this flow is supervised by instructions and quality control documents.

Some production processes can not always be verified by subsequent control and testing and therefore need continuous supervision. Examples of such processes are:

- Heat treatment
- Surface treatment
- Adhesive bonding
- Composite manufacturing
- Welding
- Shot-peening and blasting
- Forming
- Chemical milling

These processes are extensively examined and qualified. Special requirements on authorized personnel, work-shops, equipment, environment, etc. exists.

Special routines for items produced in these processes are also carried-out before series-manufacturing is started in order to qualify the process to that specific item. Systematic procedures and documentation of the process is done. The item is checked against design and production instructions, correctness of tools and suitability of process.

For some processes, destructive testing is done on the first item which has been produced in the complete process. This item is cut in parts and tested in laboratory.

A complicated process like the automated process for bonding metal panels includes moments such as handling, cleaning, surface treatment, application of primers and adhesive and curing, and are carefully supervised. Each panel is followed through the complete process by specimens for destructive testing. Each individual panel is also 100% scanned by transmission ultrasonic equipments.

6. STRUCTURAL MAINTENANCE PROGRAMME

6.1 Structural maintenance concept

The Saab 340 structural maintenance programme was developed to satisfy the requirements for damage tolerance that were new at the time for certification. This required the development of new procedures for determining the adequacy of the inspection program for timely detection of damage. The major forms of damage considered during the program development were environmental deterioration (corrosion, stress corrosion), accidental damage and fatigue damage. The results of these analyses gave the initial scheduled maintenance programme for Structural Significant Items (SSI) and zone surveillance. The programme was developed according to the philosophy and logic in the ATA MSG-3 document.

6.2 The MSG-3 analysis

6.2.1 Structural analysis logic

The structural analysis logic is shown in figure 12 and consists of the following tasks:

- List per ATA 100 all structure
- Categorize items as Structural Significant Items "SSI" or as other structure.
- Document each SSI:
  - Illustrations
  - Function
  - Stress characteristics/level
  - Material & Manufacturing process
  - Protection
- Classify SSI´s as damage tolerant or safe life structure
- Check if SSI´s are fatigue, environmental or accidental critical.
- Perform fatigue damage analysis for damage tolerant items
- Select safe life limit for safe life items
- Perform environmental damage analysis for damage tolerant and safe life items
- Perform accidental damage analysis for damage tolerant and safe life items
- Summary of SSI inspection tasks on SSI Task Summary Sheet

The considerations to be taken into account when selecting SSI candidates are given according to the logic flow diagram shown in figure 13.

6.2.2 Fatigue damage analysis procedure

Fatigue critical items are items which are significantly loaded in tension or shear. The fatigue damage analysis procedure follows the philosophy and principles developed in the MSG-3 document. Therefore the tasks necessary to ensure an appropriate fatigue damage detection, are selected based on calculations and ratings of the following main parameters:

- Critical crack length
- Threshold associated with the detectable size of fatigue damage
- Crack growth assessment for repeat inspection intervals
- Detectable damage size in relation to the various levels of inspection
- Target values for scheduled maintenance intervals

6.2.3 Environmental damage analysis procedure

Environmental critical items are only those items made of less corrosion resistant materials. The environmental damage analysis procedure follows the philosolphy and principles as stated in the ATA MSG-3 document. Necessary tasks to ensure the appropriate detection of environmental damages are selected based on a rating system with the following parameters:

- Susceptibility to various types of corrosion
- Type of protective treatments
- Exposure to adverse type of environment

6.2.4 Accidental damage analysis procedure

Accidental critical items are those items which are likely to be damaged by accidental damage. Manufacturing defects are considered completely random and are supposed to occur on any aircraft at any location. Therefore such defects are taken care of in the damage tolerance analysis and are covered by the fatigue damage analysis items. Accidental damages other than manufacturing defects are also occurring as a random discrete event during operation and maintenance and reduce the inherent level of residual strength. Large size accidental damages caused by engine and propeller disintegration, bird strike and major collision with ground equipment are covered by specific regulations which require evaluation of residual strength capability for short periods of time.

The tasks to ensure detection of accidental damages are determined using a rating system including the following parameters:

- Kind of damage (Cargo handling, runway debris etc)
- Likelihood of accidental damage
- Extent of residual strength.
- Crack growth rate

6.3 The maintenance review board report

The tasks that are results of the MSG-3 analysis are included in the Maintenance Review Board (MRB) Report, Saab 340 Maintenance Programme, which is the document that outlines the initial maintenance requirements approved by the regulatory authorities.

6.3.1 Structural inspection programme.

Tasks that according to the MSG-3 analyses are defined as directed inspections (detailed or special detailed) are included in "Structural Inspection Programme". Examples of detail inspections in the Saab 340 structural inspection programme are shown in figure 14.

For Saab 340, the threshold for first inspection is in general 16000 flights. Other thresholds are 28000 and 40000 flights. Repeat intervals are 3000, 6000 and 12000 flights.

6.3.2 Zonal inspection programme.

Inspection tasks for which general visual inspections, were judged to be appropriate are transferred to the Zonal Inspection Programme.

Threshold and repeat intervals for environmental damage inspection in general are 6 and 4 years respectively. Accidental damage inspection, in general, refers to LC, A, B and C check.

7. MANUALS AND CUSTOMER SUPPORT

7.1 Structural repair manual

A structural repair manual has been prepared in accordance with ATA 100 specification to include descriptive information and specific instructions and data relative to the field repair of the structure of the Saab 340 aircraft.

It contains structural material identification, allowable structural damage criteria and repair designs applicable to structural components of the aircraft that are most likely to be damaged. In addition, it contains procedures to be performed during structural repair such as fastener installation, protective treatment and sealing of repair parts and other processes.

Based on field experience of fatigue, environmental and accidental damages the manual is continuously updated with new repair schemes

7.2 Corrosion prevention manual

In order to comply with the need to set up corrosion control programmes to ageing aircraft, a corrosion prevention manual is being prepared. The manual will give complete coverage for:

o Identification and type of corrosion
o Corrosion prevention
o Inspection and detection
o Corrosion removal techniques

The manual is planned to be released during the second half of 1992.

7.3 Customer support

For special repairs not covered by the structural repair manual, the operators of the Saab 340 are assisted 24 hours a day by a Saab Product Support Team with experience from stress engineering as well as practical structural repair. The team is also backed up by Saab Aircraft Division Stress Analysis & Testing, Airframe Design & Engineering Technology and Materials & Process Technology departments.

Saab personnel are also on site for assistance and training when the first structural inspection, at 16,000 flights, is made for the first time for each operator.

8. FEEDBACK FROM OPERATORS

8.1 The age exploration programme - AEP

This programme is used to systematically evaluate inspection tasks based on analysis of collected information from in-service experience. The programme can be performed by individual operators or by groups of smaller operators.

It is used for environmental deterioration surveillance and to assess an items resistance to environmental deterioration with respect to increasing age. Inspection of the oldest aircraft of the fleet will give the most rapid data from in-service experience and should lead to minimizing of the total number of required inspections.

AEP will only apply to environmental damage having a systematical characteristic. This means that damages occurring on a random basis caused by stress corrosion, corrosion from fluid spillage and other accidental damages can not be evaluated by this program. AEP will only apply when directed inspections are judged as necessary. If no damages are found only zonal inspection will be needed for those aircraft not subject to this program.

8.2 Reporting of structural damages

All significant structural discrepancies will be reported by the procedures already established by the airworthiness authorities e.g. Service Difficulty Reports.

Each operator is requested according to the MRB document to report to Saab discrepancies found during scheduled inspections. Where practical, details of the damages found and the inspection methods used should be reported as well as any other damage found by subsequent examination.

8.3 Special investigation of the operational usage.

The fatigue and damage tolerance sizing of Saab 340 was based on a usage defined already in the project phase, early 1980. The missions, which were considered to be conservative at that time, consist of flights distributed on four cruise altitudes having an average flight time of 30 minutes.

It is supposed that the difference in usage between individual operators might be significant for commuter aircraft. Therefore, in order to validate the fatigue spectra for Saab 340A, an inquiry about the operational usage among the operators was performed during Nov. 1988 to Nov. 1989. By assistance of Saab Product Support, the following information was requested:

- Routes and corresponding distance, flight time, cruise altitude, no. of flights per week.
- Weight and CG:load sheets (weight and balance) from representative airports.
- Power application at take off and use of reverse at landing.
- Settings for take off flap, approach flap and landing flap.
- Speeds for retraction of take off flap and for extension of approach flap, landing flap and landing gear.
- Speeds for climb, cruise and descent.

Information was received from more than 80% of the operators, thus forming a good base for the statistics.

The investigation revealed a larger portion of flights at high altitudes, and consequently a more severe cabin pressurization spectrum, than anticipated during the design phase of the aircraft.

A fatigue investigation was done which resulted in an update of the cabin pressurization design spectrum. This led also to an update of the cabin pressurization of the full-scale fatigue test at 120,000 simulated flights. Additional pressurization cycles were applied before the restart with the new spectrum in order to simulate a more severe loading from the beginning of the test.

A review of all damage tolerance analysis which was affected of this change in spectrum was also done. The damage tolerance analysis for Saab 340B was done from the beginning with the new spectrum.

Referring to the figure 4, this is an example of how the feedback from field experiences is integrated in the fatigue and damage tolerance sizing concept resulting in a preserved control of the structural integrity.

ACKNOWLEDGEMENTS

This paper presents an approach, which comprises different technologies at Saab Aircraft and is a result of a joint effort. Those who have contributed to this paper are gratefully acknowledged. Major contributions were prepared by Mr Göte Strindberg, Engineering Technology, Mr Einar Hultgren, Materials and process technology, Mr Göran Prestby, Stress Analysis Commercial Aircraft, Mr Lars Sjöström, Loads and structural analysis technology, Mr Göran Lindström and Mr Håkan Persson, Saab Product Support.

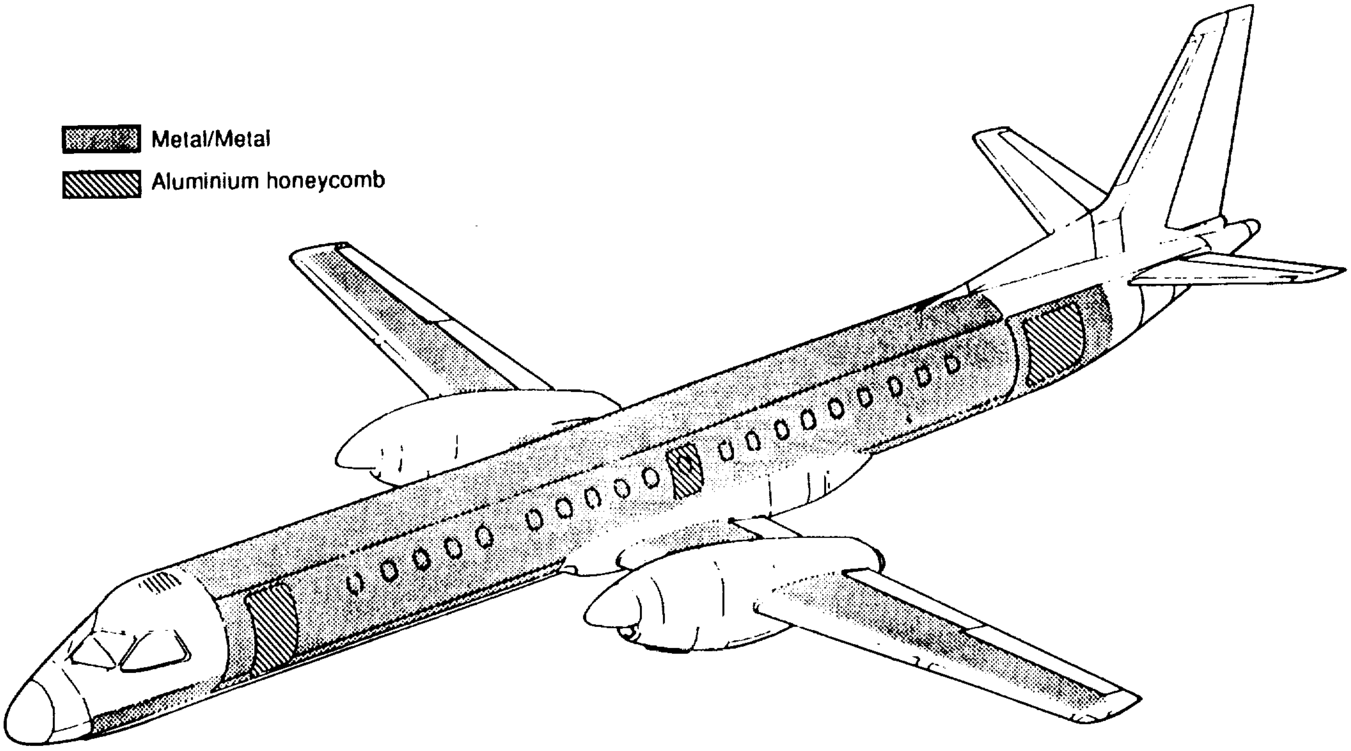


Figure 1. The metal to metal bonded structure on Saab 340

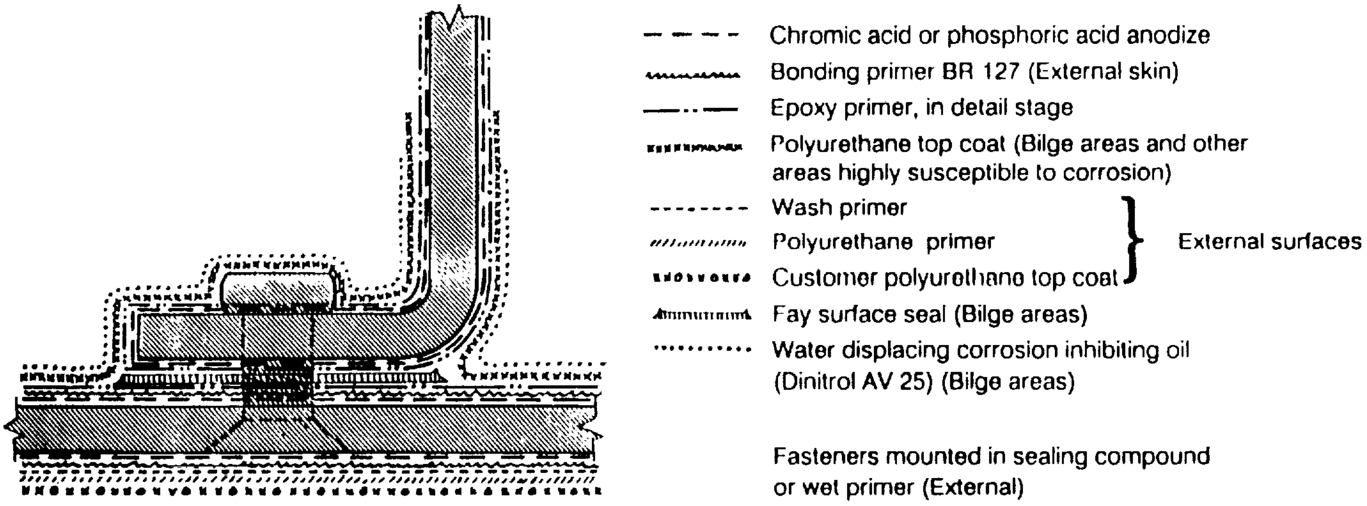


Figure 2. The corrosion protection scheme

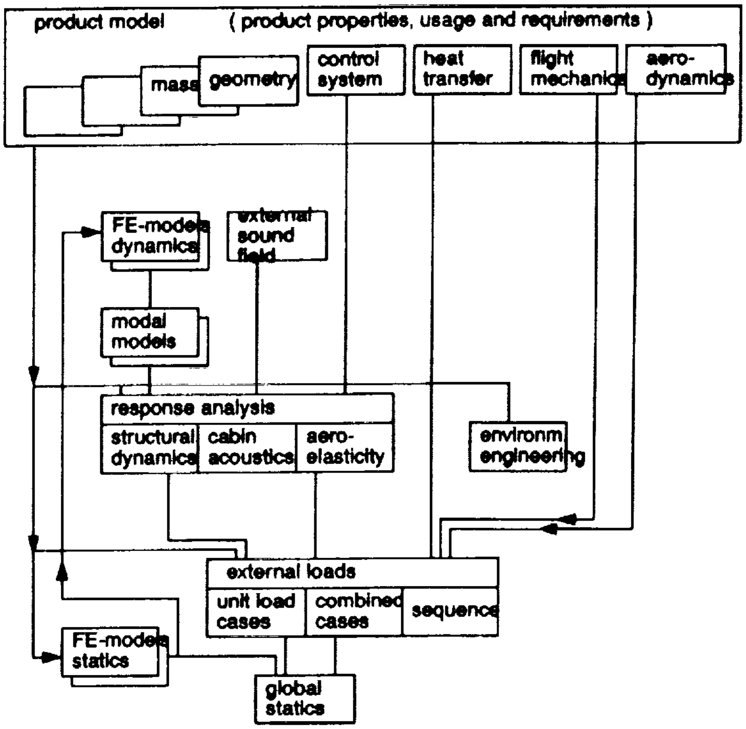


Figure 3. The current basic process for loads analysis

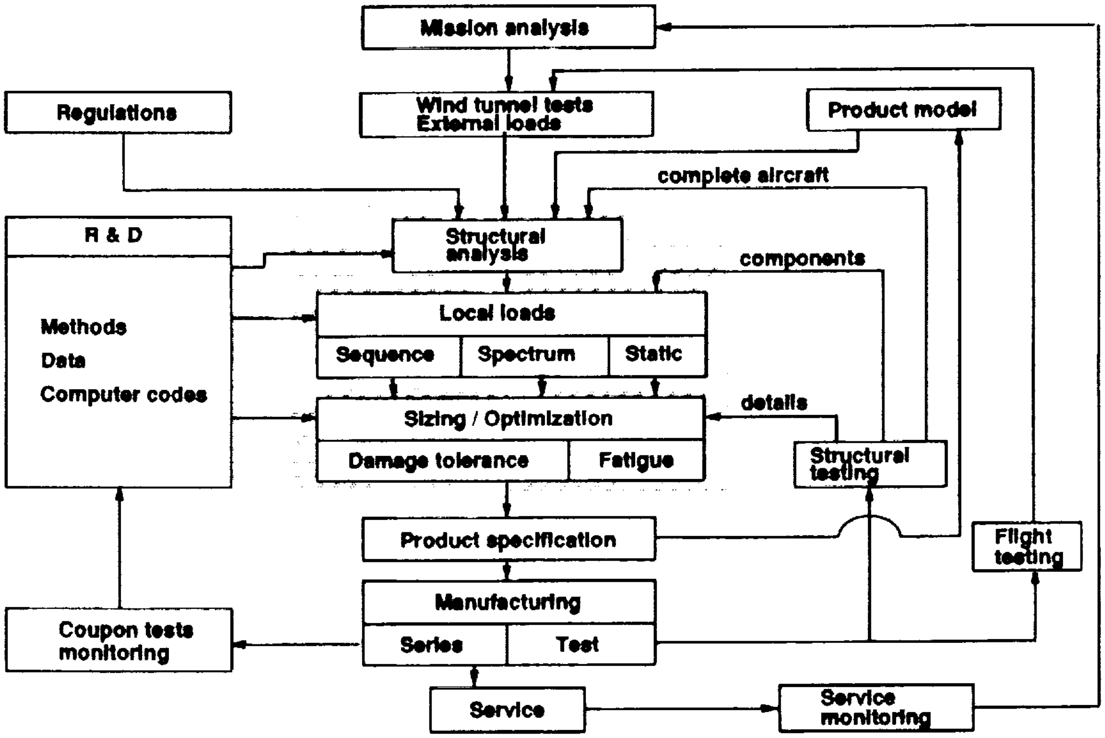


Figure 4. The sizing and verification concept

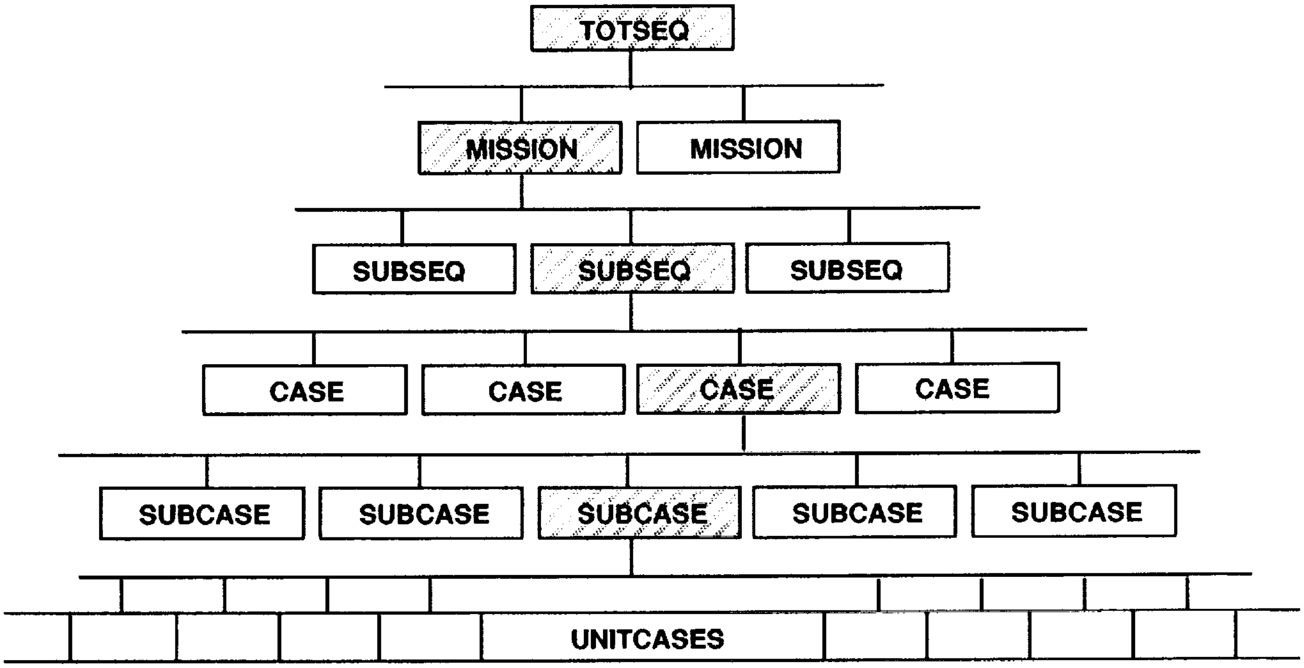


Figure 5. The hierarchic structure of the global sequence

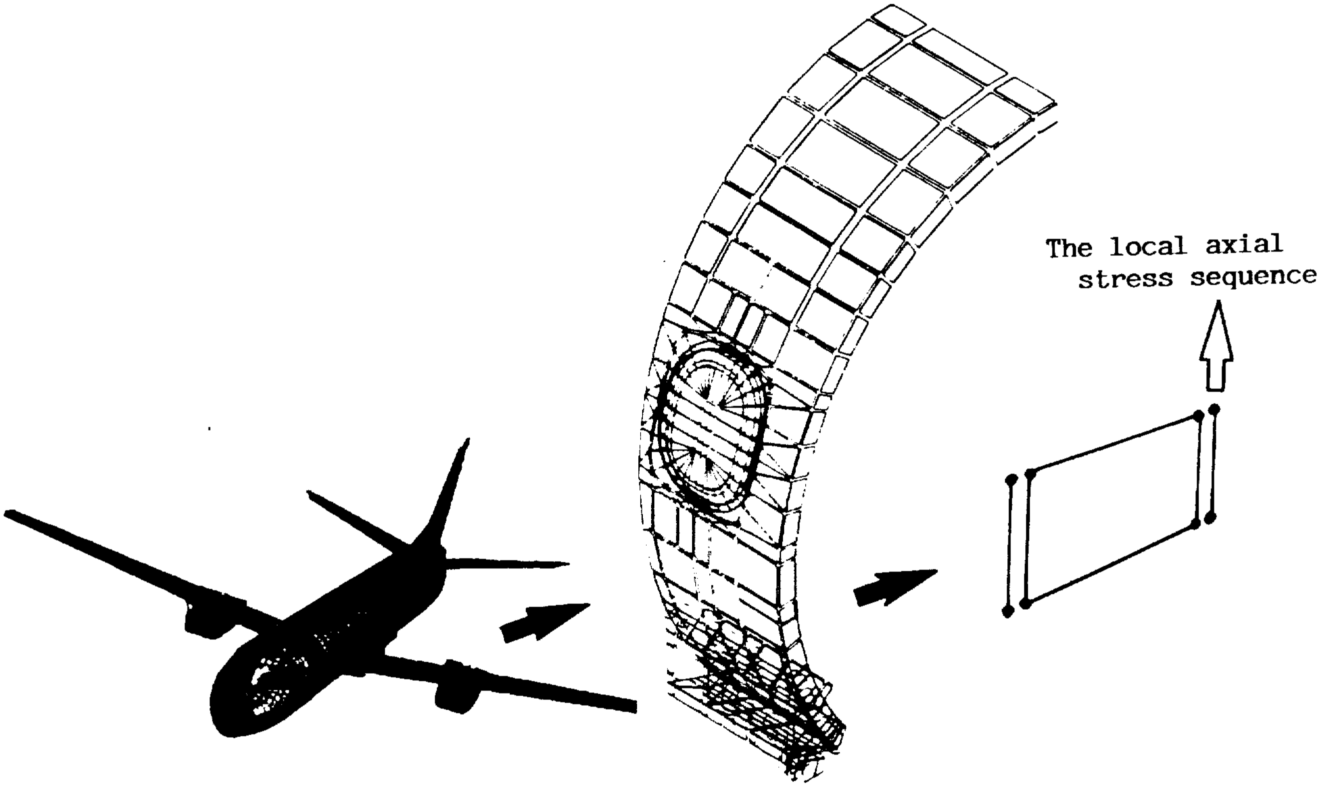


Figure 6. A substructure of the finite element model of Saab 2000

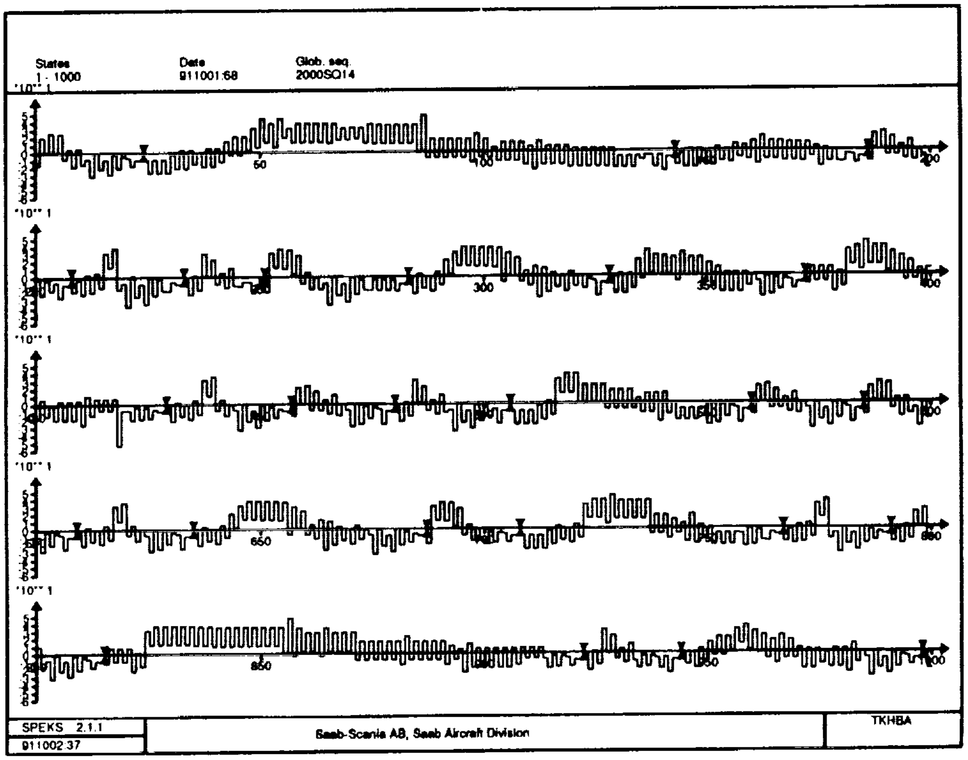


Figure 7. A part of the reduced local axial stress sequence of the inner flange.

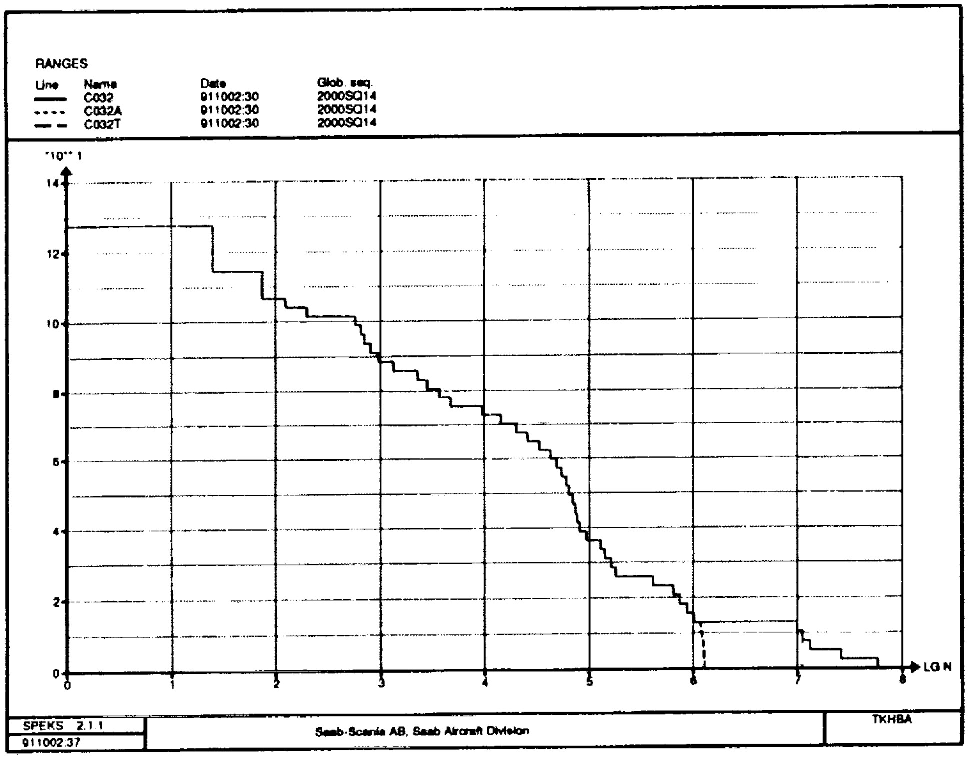


Figure 8. The distribution of rain-flow counted ranges for the original and reduced sequence.

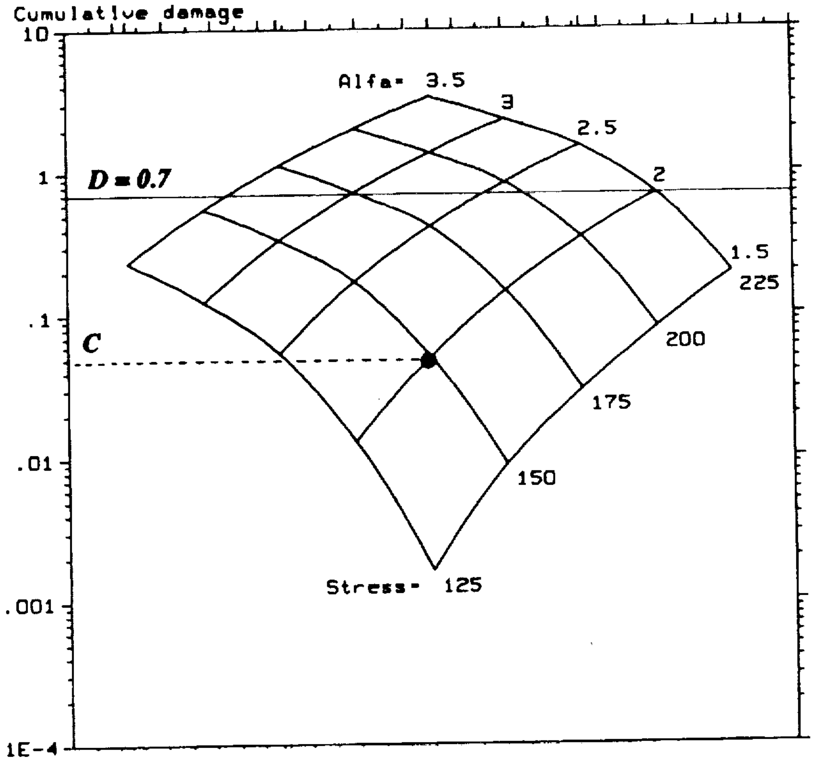


Figure 9. A plot of cumulative damage sums

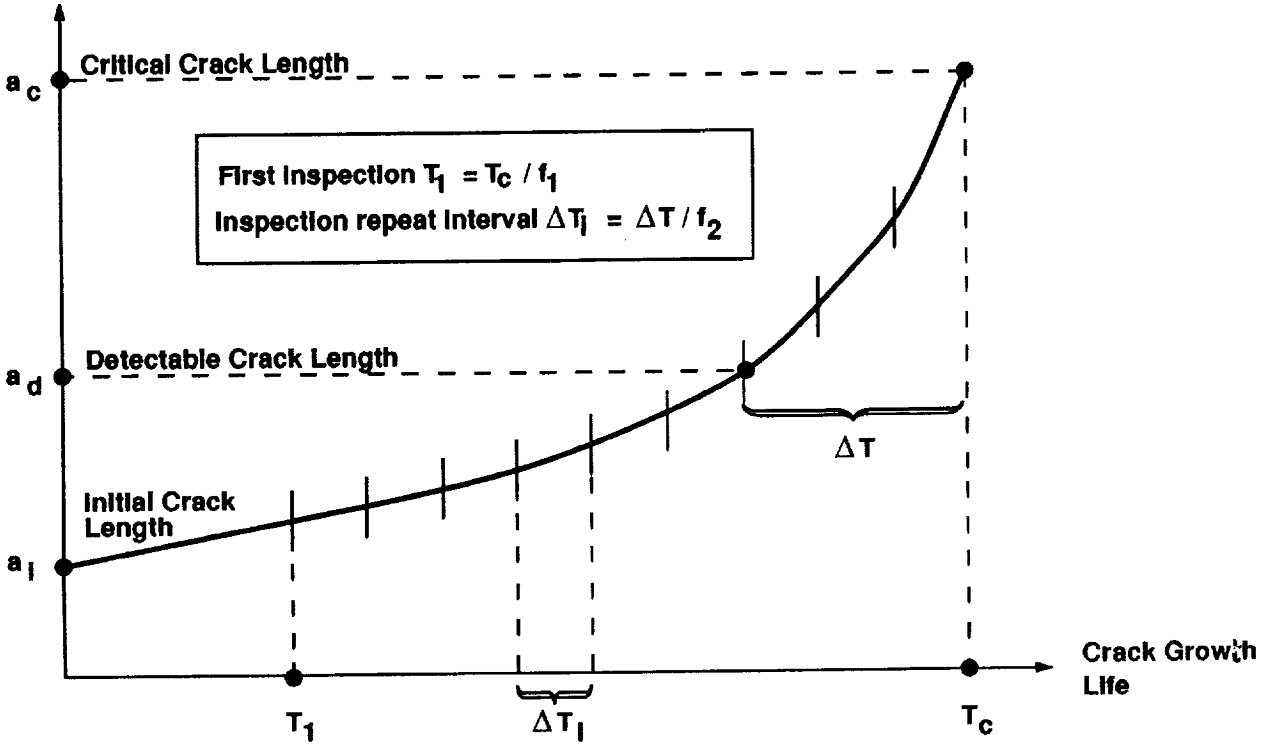


Figure 10. The crack growth curve with threshold and inspection repeat intervals

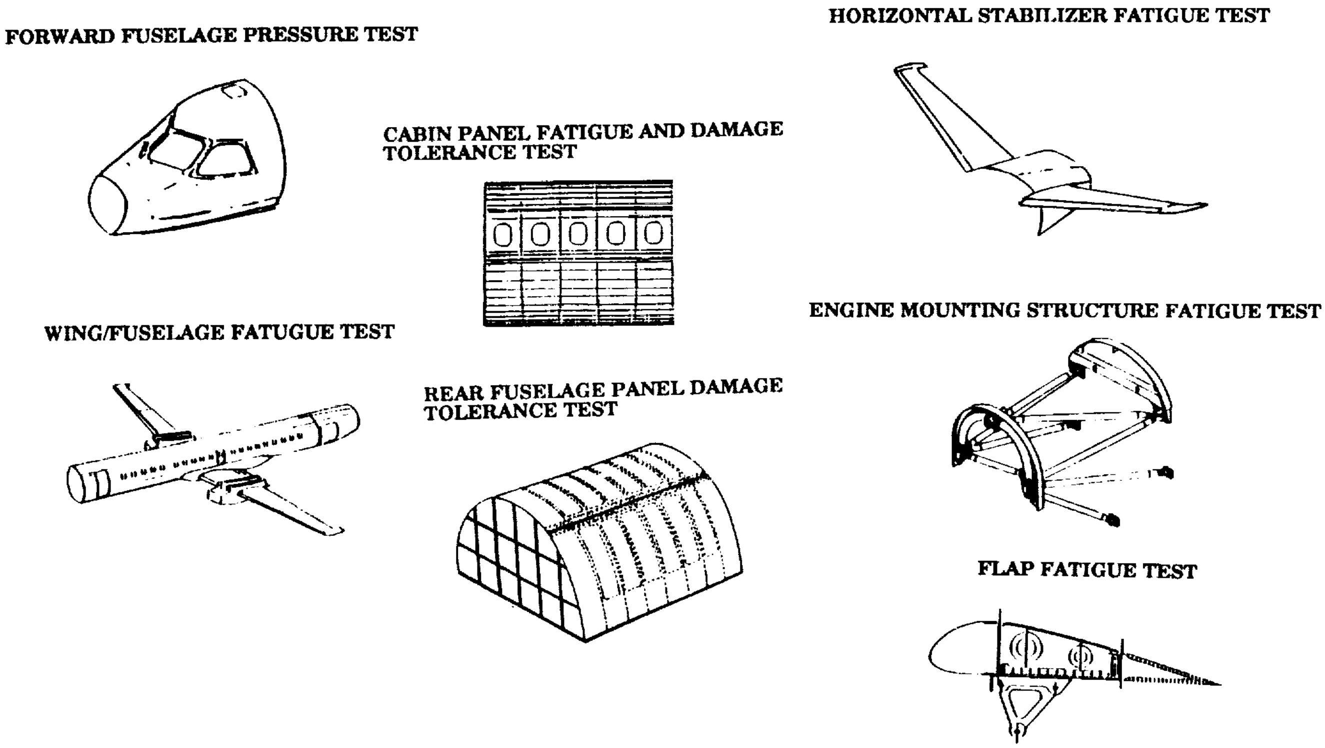


Figure 11. Major fatigue and damage tolerance tests on Saab 2000

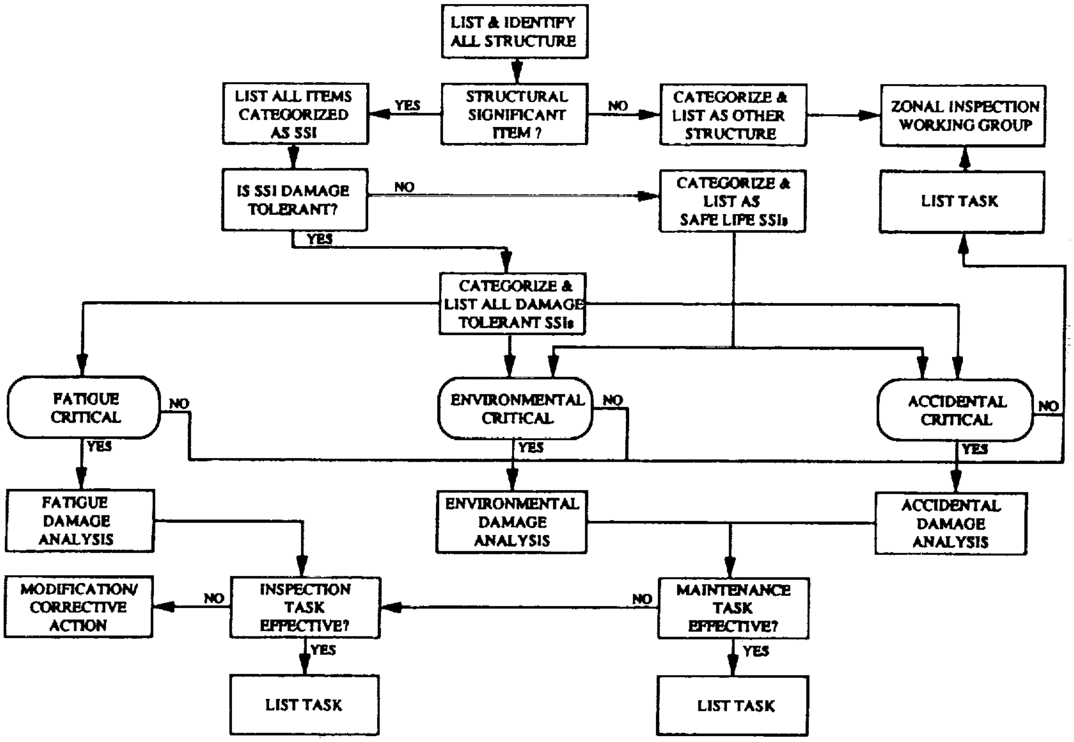


Figure 12. The MSG-3 structural analysis logic

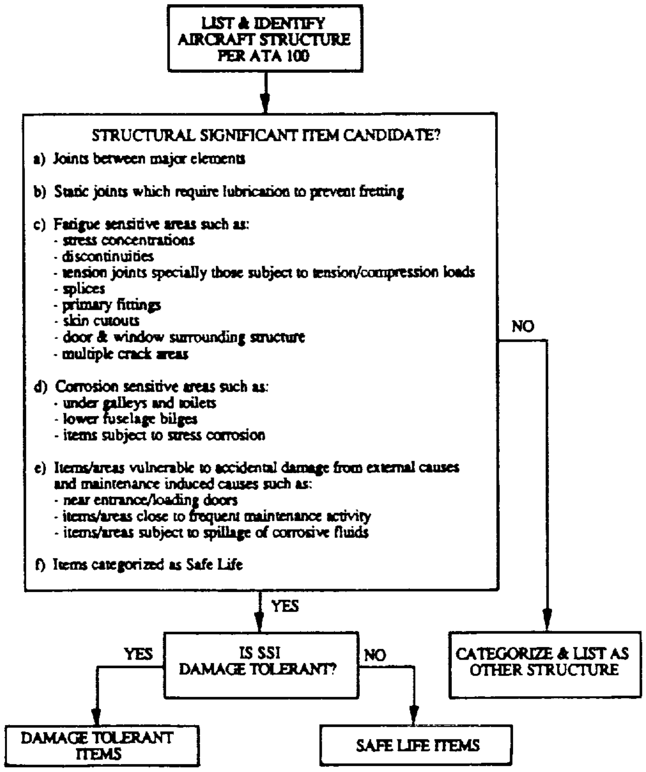
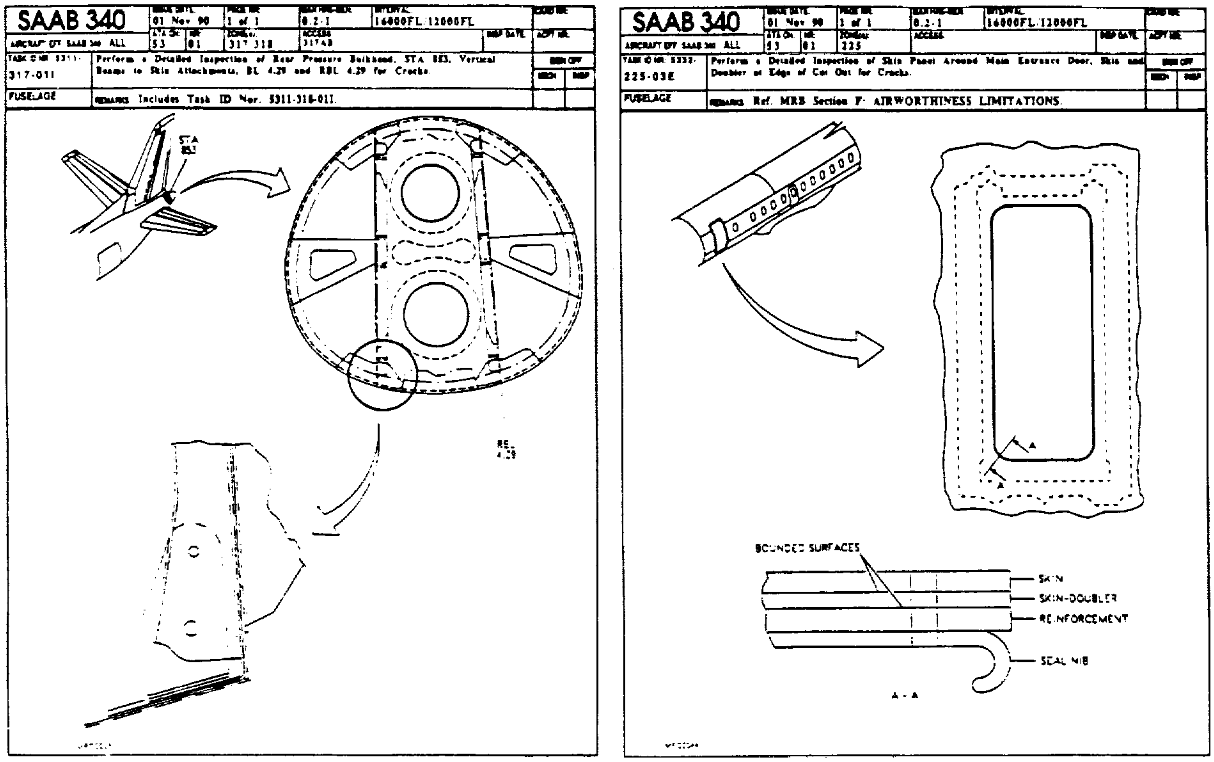


Figure 13. The logic flow diagram for selecting SSI candidates.



SAAB 340
AIRCRAFT EFF SAAB 340 ALL
01 Nov 90
1 of 1
0.2-1
16000FL/12000FL
53
01
317 318
317AB
TASK ID NR 5311-317-011
Perform a Detailed Inspection of Rear Pressure Bulkhead, STA [illegible], Vertical Beams to Skin Attachments, BL 4.29 and RBL 4.29 for Cracks.
FUSELAGE
REMARKS Includes Task ID Nr. 5311-318-011.

SAAB 340
AIRCRAFT EFF SAAB 340 ALL
01 Nov 90
1 of 1
0.2-1
16000FL/12000FL
53
01
225
TASK ID NR 5332-225-03E
Perform a Detailed Inspection of Skin Panel Around Main Entrance Door, Skin and Doubler at Edge of Cut Out for Cracks.
FUSELAGE
REMARKS Ref. MRB Section F- AIRWORTHINESS LIMITATIONS.

Figure 14. Examples of detail inspections.