

## Integrated Logistic Support Approach of Wear-Related Problems

**Nicolas CHRETIEN (Author) and Frederic ABSI (Co-author)**

78, Quai Marcel Dassault  
92552 St. Cloud Cedex 300  
FRANCE

[nicolas.chretien@dassault-aviation.fr](mailto:nicolas.chretien@dassault-aviation.fr)  
[frederic.absi@dassault-aviation.fr](mailto:frederic.absi@dassault-aviation.fr)

### ABSTRACT

*Integrated logistic support aims at anticipating wear and erosion damages during operational use of the aircraft through a concurrent engineering process. Throughout the aircraft's life cycle, a close interaction between engineering studies and in-service experience leads to a better understanding of wear-related problems. The result is a fully integrated approach increasing aircraft operational availability and reducing maintenance costs. This paper shows typical examples of mechanical and environmental wear that can be found on aircraft's structures and presents the solutions that have been developed to overcome these phenomena. These solutions involve routine maintenance procedures that should be performed on a regular basis to prevent potential wear damages and specific maintenance procedures to correct existing problems. The document also describes the control methodology designed to detect and predict the onset and growth of surface damages introduced by abrasion, wear and erosion.*

### 1.0 INTRODUCTION

Integrated logistic support is a composite of all the support considerations necessary to ensure efficient and economical support of an aircraft throughout its life cycle. One of these considerations is to anticipate future problems related to aircraft operational use to provide the highest level of fleet availability at minimum operating costs.

Accordingly, the major concern of an aircraft manufacturer with regard to wear<sup>1</sup>, is to focus on the early detection of wear and the implementation of effective wear control and mitigation practices so as to drastically reduce unscheduled repairs, replacement costs and aircraft downtime. This is achieved through a concurrent engineering approach, based on aircraft in-service experience and specific maintenance studies, which leads to a progressive maintenance scheme.

To reduce the economic burden of maintenance operations, wear mitigation is initiated at the preliminary stage of aircraft design through a judicious selection of elemental materials and protective coatings. However, as these solutions can only delay wear but not prevent it, two objectives must prevail in terms of aircraft support :

- Prevent wear through an effective maintenance plan (preventive measures)
- Fight wear during aircraft operational use (corrective measures)

These two precepts are the foundation of a successful integrated logistic support approach.

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<sup>1</sup> To reduce the scope of this analysis, this article focuses on aircraft structures and materials and does not address wear issues related to aircraft equipment (engine, electrical appliances, etc.).

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## 2.0 PREVENTIVE MAINTENANCE APPROACH

Preventive maintenance operations are programmed through an initial maintenance plan, based on an analytical method inspired by MSG3 methodology. This method allows to analyze each structurally significant item of the aircraft and take into account its sensitiveness to the following deterioration processes<sup>2</sup>:

- Wear and fretting between contacting surfaces in mechanical assemblies (e.g. hinges or "stiff" assemblies such as bushing and tapered shafts)
- Environmental wear, such as abrasive wear or erosion on external panels caused by sand, hail or wind (aerodynamical erosion)

The sensitiveness of each element to the above deterioration process is evaluated partially or totally through a notation system based on influential parameters. This notation, along with test and computation results, is translated into periodicities and samples. Each scheduled operation is thus related to a specific periodicity and can be performed either on the fleet as a whole (systematic operations) or on a sample of it (sampling operations), depending on the notation. Scheduled operations can be gathered under common visits (e.g. Major Visits (MV) , Partial Visits (PV), Intermediate Visits (IV), etc.) to minimize aircraft grounding time.

### 2.1 Systematic Operations

Systematic operations allow to oversee and prevent wear through scheduled controls or routine maintenance procedures. These operations allow to keep the safety level above an admissible threshold with the objective of minimum maintenance costs. They reveal damages that could occur during servicing and could not be detected during operating level maintenance inspections. Each inspection is followed by an analysis to assess the impact on preventive maintenance.

#### 2.1.1 Wear Controls

These operations can be carried out zone by zone, taking advantage of the fact that the aircraft is grounded for a periodic maintenance inspection requiring opening of several doors.

Scheduled controls related to wear consist mainly in in-depth visual inspections and punctually, if necessary, in dimensional controls intended to determine the amount of wear quantitatively.

##### 2.1.1.1 Visual Inspection

A visual inspection is the simplest means of testing the condition of a structural component. In spite of its seeming simplicity, it should not be underestimated as it is the most frequently used and the most reliable means of non-destructive testing.

Other testing methods are only performed to quantify the amount of wear; they should always be preceded by a visual inspection intended to point out any defects which might affect test performance (poor surface finish, corrosion, etc.).

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<sup>2</sup> Corrosive wear in which both corrosion and wear mechanisms are involved is not addressed in this paper. However the sensitiveness to this deterioration process is also taken into account within the scope of MSG3 analysis. For more information on corrosive wear phenomena, readers should refer to ASM Handbook, Vol. 18, "Friction, Lubrication, and Wear Technology", 1992.

The operator performs a visual inspection with sufficient lighting and optical equipment deemed necessary, to find visible external flaws, such as :

- erosion or abrasion of paint, putty or external skin,
- disappearance of antifretting protective coating,
- disappearance of anticorrosion protective coating,
- reduction of load bearing cross-section, etc.

Specialized equipment, such as miniature cameras or endoscopes of different types, can be used to perform visual inspections in areas with low accessibility and visibility (e.g. bays, integral tanks, air ducts).

If a defect is detected, the damaged element can either be repaired or replaced, depending on the extent of the damage. Any area judged defective is subjected to an in-depth inspection (further items removed and/or paint stripped) or check.

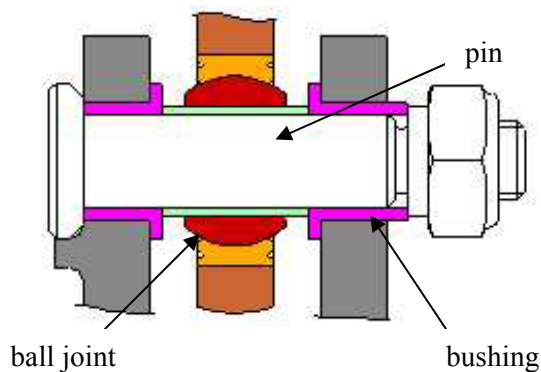
If no defects are detected, the elements are left in condition with possible application of protection on external skins and panels or greasing and lubrication of hinge components.

#### 2.1.1.2 Dimensional Check

Dimensional checks enable to quantify the amount of wear and fretting in mechanical assemblies, especially in loaded hinges.

For structural parts of the airframe, wear is not quantified over a strict measurement (such as weight loss or area measures) but over geometrical criteria (excessive play of a bore, shaft parallelism, ovalization of bushes or bearing fittings, etc.).

#### Example : dimensional checks of hinges



**Fig. 1 Rafale Rudder Bearing Representation**

Dimensional checks are to be performed only when visual inspection of hinge components discloses an anomaly (wear, peening, etc.), anomaly leading to an excessive, but not detrimental, play.

Accessibility, sizes and tolerances are specific to each hinge and are specified in the aircraft maintenance documentation.

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The equipment required for these inspections are :

- Bore measuring tools
- Outside micrometers for measuring pins or shafts
- Slip gauge for checking outside micrometers
- Reference cylindrical bushings for calibrating bore measuring tools

Dimensional check of hinges consists in measuring the various hinge components using the related instruments and proceeding as follows:

### *Bore inside Diameter and Out-of-Round Measurement :*

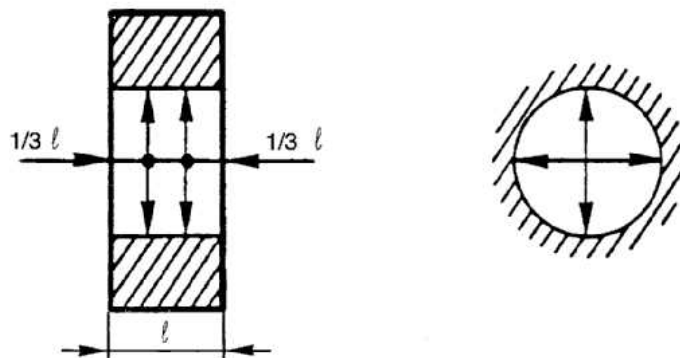
With the bore measuring tool, the operator measures the inside diameter of the reamed bore, at one third of the length at each end of the bore, on two perpendicular planes (see Fig. 2). He then records each measurement (4 measuring values  $\phi 1$ ,  $\phi 2$ ,  $\phi 3$ ,  $\phi 4$ ) and performs the following calculation :

Calculation of bore mean inside diameter ( $\phi_m$ ) :

$$\phi_m = \frac{\phi 1 + \phi 2 + \phi 3 + \phi 4}{4}$$

Calculation of maximum wearing out-of-round  $\Omega$  :

$$\Omega = \phi_{\max} - \phi_{\min}$$



**Fig. 2 Bore inside diameter measures**

### *Pin, Bush, Bearing or Balljoint Diameters Measurement :*

With the micrometer, the operator measures the outside diameter of the pin, at one third of the length at each end of the pin, on two perpendicular planes (see Fig. 3). He then records each measurement (4 measuring values  $\phi 1$ ,  $\phi 2$ ,  $\phi 3$ ,  $\phi 4$ ) and performs the following calculation :

Calculation of center pin mean outside diameter ( $\phi_m$ ) :

$$\phi_m = \frac{\phi_1 + \phi_2 + \phi_3 + \phi_4}{4}$$

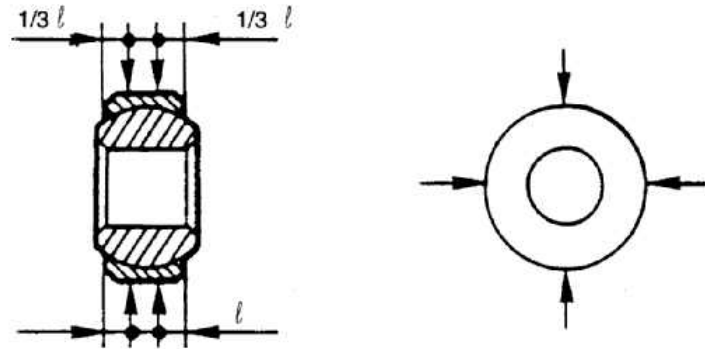


Fig. 3 Pin outside diameter measures

The operator analyzes the difference between the two mean diameters and the out-of-round value of the damaged elements, and, according to the criteria mentioned in the maintenance documentation or in general assembly drawings, decides either :

- reinstallation on aircraft (with potential repair), or
- replacement of equipment or overhaul.

For example, during a periodic visit, traces of wear were found on Alphajet engine/fuselage interconnecting components (trunnions). A dimensional control was performed to establish the loss in material. The first measurement (mark 1 on Fig. 4) was out of tolerance (24.960 mm for 24.970 mm admissible). A second measurement (mark 2 on Fig. 4) was performed to check the extent of the worn area. This measurement was inside tolerances (24.980 for 24.970 mm admissible). However, as one of the measurements was out of tolerance, and since this element is highly critical for the aircraft, the trunnions were replaced. A systematic dimensional check of these elements during periodic visits was also added to the Alphajet maintenance plan.

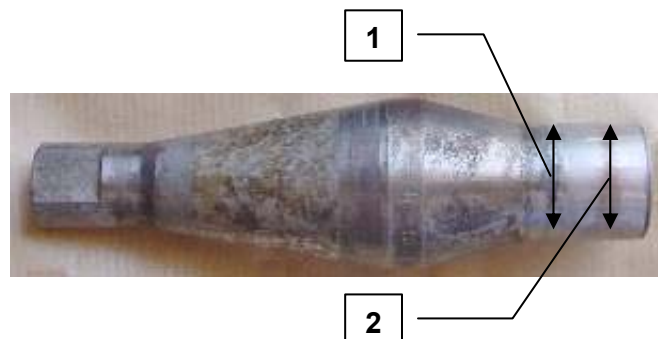


Fig. 4 Alphajet engine/fuselage interconnecting trunnion

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**2.1.2 Wear Maintenance Procedures**

Routine maintenance procedures related to wear consist mainly in lubrication and greasing visits. The choice of appropriate lubricants and greases depend on cost, health, safety and environmental considerations. Minimizing the number of lubricants used on an aircraft simplifies maintenance operations and reduces inventory storage and handling.

The different types of greases and lubricants used on Dassault aircraft include :

- Mineral "extreme pressure" grease (ester type) on frequently solicited hinges, such as elevon bearings.
- Synthetic hydrocarbon grease for most mechanical hinges.
- Mineral oil for mechanisms.

On the Mirage 2000, two main visits are scheduled :

- a Greasing Visit (GV) every 6 or 8 months, and
- a Complementary Greasing Visit (CGV) during Intermediate Visit (IV) every year.

This implies that each mechanical assembly and mechanism has to be visited at least once a year.

On the Rafale, thanks to a comprehensive analysis of each mechanical element and thanks to other aircraft in-service experience, two greasing visits are scheduled, but at very distant date-lines :

- a Greasing Visit (GV) every 6 months, and
- a Complementary Greasing Visit (CGV) every 4 years.

This implies that for less critical mechanisms or assemblies (with respect to MSG3 analysis), greasing visits can be postponed to four years after the preceding visits.

Lubrication of frequently solicited and critical mechanisms is also scheduled during daily visit (arrestor hook, canopy rollers...) to protect these elements in-between two inspections.

**2.2 Sampling Operations**

Sampling operations serve as ageing studies to consolidate the maintenance plan. The outcome of these inspections can have an influence on its content. In this manner, this evolutive plan is combining with a progressive maintenance concept, based on an adapted sampling program.

Sampling operations can also be conducted to update scheduled systematic operations content at the beginning of an inspection program. A good example of this concurrent analysis is an ageing study that was performed on three Indian Air Force Mirage 2000 during their first major inspection in September 1992. The objective of this study was to assess the influence of the local environment in which the aircraft had been operated, and to clearly define the maintenance operations to be carried out on the remaining Indian Mirages, during their first major inspection (programmed 7 years after their first operation).

The main observations in connection with wear damages and the repercussions and proposals for the first major inspection were :

- Wear and excessive play found on bearing bushes and ball joints. As a result, the replacement of incriminated bushes and measurement of hinge bearings was recommended for the first major inspection.

- Degradation of protection elastomers (e.g. slat seals, cockpit padding, shock absorbers on electrical units). Corresponding replacement spares were recommended for the first major inspection.

Skin inspection : some traces of wear and loss of protection were found, mainly around the wing root, fuselage and fin root fairing areas. These elements were carefully inspected for the first major inspection and, depending upon condition, the coatings were rubbed down and the protection reapplied.

In addition to these inspections, a specific ageing study was conducted on hinges and bearings to determine the state of wear of hinged and non-hinged links on aircraft, by a dimensional check. This measurement of wear, oval play and peening, and experience gained on French Air Force aircraft provided the basis for the definition of dimensional criteria as well as shaft/bore clearances, acceptable on the first major inspection and resulting in an expected serviceability of at least nine years.

The study carried out on the three aircraft provided a good evaluation of the aircraft actual wear level with regard to its environment. The damages suffered by the aircraft were reported to be similar to those encountered in the French Air Force and the effects of the local environment were thus estimated to be moderate.

### 3.0 CORRECTIVE MAINTENANCE APPROACH

It is emphasized that an efficient program is one, which schedules only those tasks necessary to meet the stated objectives. It does not schedule additional tasks, which will increase maintenance costs without a corresponding increase in reliability protection.

To reduce preventive measures workload to its necessary minimum, a tolerance damage concept (for quantifiable damages) is applied to the airframe design. A damage tolerance analysis of structurally significant items subject to wear leads to the definition of acceptability and reparability criteria for corresponding wear damages.

Damages are identified with the same techniques used for preventive maintenance inspections. The important point is to determine the exact extent of wear (qualitatively or quantitatively).

Wear damages are listed in two categories :

- Acceptable damages have no influence on the structure mechanical behavior or aircraft performances. They can be left in condition with possible application of renewable protections.
- Repairable damages have to be repaired at first opportunity and can be performed without constructor's notice.

For hinges, damage tolerances are based on general assembly drawings, which give maximum and minimum nominal dimensions of hinge elements, and maximum and minimum play between contacting surfaces. Specific tolerances (e.g. in terms of ovalization) can also be given for critical or vital hinge components based on damage tolerance assessments of older aircraft.

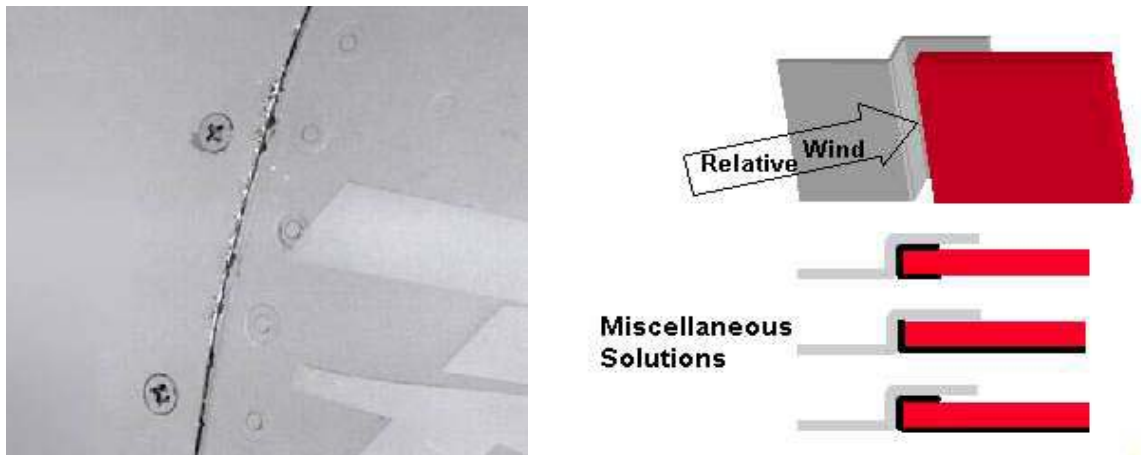
For environmental wear damages (including wear of gaskets and joints in mechanisms), tolerance criteria can not always be given, and it is often the operator's choice to decide whether or not the element should be repaired. The acceptability of such damages is related to the functions (aerodynamical, structural, sealing or discretion) of the damaged part. If these functions are not corrupted, the element can be left in condition with possible protection renewing. If one of these functions is corrupted, the repair should restore the integrity of the element, with respect to this function.



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Examples of wear-related repairs on aircraft are various :

- Rafale front fuselage external skins are mostly made out of kevlar composite materials, which are very sensitive to aerodynamical erosion. As a result, traces of erosive wear can occasionally be found on doors and panels leading edges. Repair solutions include damage cementing with resin for extended damages or anti-erosion adhesive reinforcement for smaller damages (see Fig. 4).



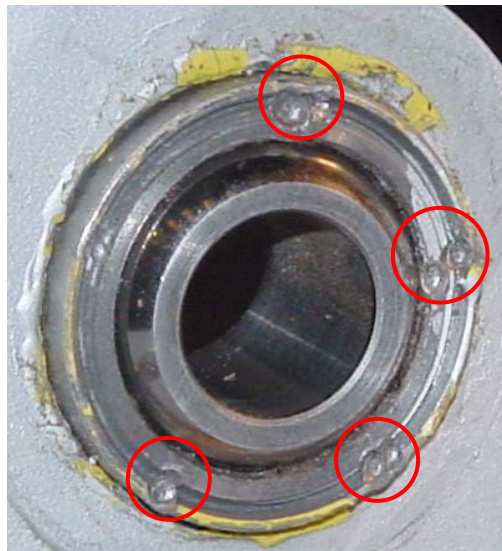
**Fig. 4 Example of Rafale door edge anti-erosion solutions**

- Fretting occurs frequently between contacting surfaces such as wing/fuselage fairing or fuselage/tail cone and wing/slats ties. Fig. 5 shows an example of contact area fretting between fuselage and tail cone on an Alphajet. In these cases, repairs consist mainly in renewal of the area protection (paint and putty, if necessary) or use of Teflon adhesive.



**Fig. 5 Fretting of contact area between Alphajet fuselage and tail cone**

- Wear can develop in hinges because of improper installation. A good example is shown on Fig. 6, with an improper ball-joint swaging on Alphajet main landing gear doors. The ball-joint was thus free to move within its reaming. As a result, the seal between fitting and ball-joint got worn out, which created risks of corrosion or cracks spreading. A thorough inspection of main landing gear doors ball-joints and bushes was performed to check for proper spot stamping of the ball joints. When the swaging was found to be incorrect, the ball-joints were replaced.



**Fig. 6 AlphaJet landing gear doors ball-joint wear**

- Wear in stiff assemblies or hinges can appear through ovalization or fretting on inner surface of a loaded reaming. A common repair solution is oversize dimension drilling of the damaged reaming. This allows to recover a flawless surface condition and prevent fatigue cracks growth without perceptibly altering the structural behaviour of the mechanical assembly. An example of fretting wear is shown (Fig. 7) on wing/fuselage main attachment fittings of a Mirage 2000. The inside diameter was extended from  $\phi = 52mm$  to  $\phi' = 53,2mm$ .



**Fig. 7 Fretting wear on Mirage 2000 wing/fuselage main attachment fitting**

#### 4.0 OPTIMIZATION WITH IN-SERVICE EXPERIENCE AND TECHNICAL PROGRESS

Corrective and preventive maintenance related to wear can be optimized thanks to in-service experience and technical progress (e.g. choice of materials and protections).

Hence, the Rafale benefits from the experience of older planes (especially the Mirage 2000 and the Falcon jets, for composite material wear) as well as the evolution of design and manufacturing techniques from Dassault Aviation.

For example, the experience of aerodynamical or contact erosion on older aircrafts (Fig. 8) allowed to integrate the choice of specific anti-erosion products into the Rafale protection plan definition, such as :

- A Celomer "Celogliss" self-lubricating paint, designed to facilitate the sliding of movable structural components in contact with each other (e.g. leading edges and slats or wing/fuselage fillets), offering high resistance against rubbing and very effective anticorrosion properties.
- An anti-erosion adhesive tape with varnish juncture to protect erosion-prone areas of the aircraft, especially antennas.



**Fig. 8 AlphaJet wing leading edge erosion (left) and Mirage F1 nose cone erosion (right)**

The relatively repeated occurrence of fretting wear on Mirage 2000 hinge bores, lead to the bush setting of every structurally significant assembly on the Rafale (e.g. controls bearings). To lower fretting effects on pins or shafts and minimize galvanic corrosion, bushes were chosen out of copper alloys and the protection on assembly (at interfaces) and after assembly (touch-up, finishing, renewable protections) was reinforced.

The Rafale program launching was also a chance to re-examine and update MSG3 methodology. For the Mirage 2000, the analysis focused on the criticality  $C$  of structural parts and mechanical assemblies. As a result, preventive operations periodicities  $P$  were mostly a function of this factor :  $P = f(C)$ . For the Rafale, a deeper analysis allowed to take into account several factors such as the type of assembly  $T$  (free, tight, loaded or not very loaded), the movements frequency  $F$  (e.g. repeatedly or occasionally solicited hinge), the assembly sensitivity to wear and fretting  $S$  (related to materials and protections of the assembly) and, of course, the criticality of the constitutive elements. As a result, the periodicities  $P$  of the programmed operations (and their content) was a function including all of these factors :  $P = f(T, F, S, C...)$ .

## 5.0 CONCLUSION

Wear is a very common but ineluctable phenomenon, in close connection with aircraft use and with high consequences on safety and on operational and economical aspects. Therefore, wear-related problems must be solved as early as possible, first on the design level thanks to a sharp choice of technologies and protections, and secondly on the maintenance definition level thanks to a comprehensive analytical approach which allows to determine an optimised maintenance plan.

All through aeronautical programs, design choices (bush setting of fittings, wear parts interchangeability, slipping varnishes, anti-erosion protections, etc.) as well as aircraft maintenance methodology (structurally significant items analysis, influential factors definition, use of ageing studies, visual inspection and updated repair solutions, etc.) progressively evolved thanks to in-service experience.

If these aspects are not taken into account upstream, they may constrain the customer to a heavy and onerous maintenance system, all along the aircraft service life. This can and must be avoided as there are easy-to-implement preventive solutions, especially by mean of simple protections (varnishes, adhesives, lubricants, etc.), that allow to restrain wear consequences, and easy-to-implement control techniques, especially by mean of visual inspections, that allow to detect wear problems before they become critical for the aircraft.

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