New Design Procedures Applied to Landing Gear Development

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A survey of the most advanced design tools and procedures applied to landing gear development is performed. This survey mainly focuses on computer-aided design (CAD) methods as used for kinematics and loads definition, performances simulation, solid modeling, and finite-element analysis. However, two other procedures are also considered, i.e., failure and reliability analysis and value analysis. It is shown how the use of these new design procedures is the only way to achieve a thorough optimization of a modern and competitive landing gear coping with stringent requirements in such different areas as kinematics, weight, safety, service life, maintainability and cost effectiveness.

Introduction

LANDING gear design first consists of the definition of a geometry adapted to the aircraft configuration, and, in particular, of kinematics, which makes it possible to retract the gear with the adequate retraction path and to reduce the overall dimensions as much as possible in the landing gear up position. The landing gear design also involves optimization of the shock absorber in order to minimize the loads on touchdown and to insure optimal ground-riding comfort.

Lastly, landing gear design involves very careful engineering and calculation of the subassemblies and the parts, which must meet the most severe requirements for safety, reliability, service life, maintainability, and weight.

The purpose of this paper is to point out how much more easily these complex and often contradictory objectives can now be achieved through the use of modern design tools which result mainly, but not exclusively, from the introduction of data processing in the design and engineering departments. Their impact upon the landing gear itself will be emphasized.

Brief Terminology

Landing gear generally consists of two main landing gears and one nose landing gear. It is then called tricycle landing gear. This is currently the most commonly used type of landing gear, with the exception of a few helicopter landing gears, which have a tail unit, and of very heavy aircraft, which can be fitted with more than two main landing gears.

A landing gear unit itself consists of a leg (with its shock absorber), a brace strut to maintain and lock the leg in the extended position and an actuating cylinder for retraction (which may be integrated into the strut when the latter is a telescopic one). Figure 1 illustrates the main landing gear designed by Messier-Hispano-Bugatti for the AMD/BA Rafale prototype aircraft.

Challenges of Landing Gear

The landing gear functions are of primary importance. However, the landing gear should perform its work as discretely as possible so that it can be (almost) forgotten.

Several challenges are shown in Fig. 2. The requirements to be met are often contradictory constraints. As a matter of fact, it is not always easy to have, on the one hand, a geometry perfectly adapted to the aircraft and, on the other hand, a simple kinematics or a long service life together with a low weight.

Of course, the landing gear designers have always had to cope with these difficulties. In order to overcome said difficulties, they rely on their experience and the skill they acquired in their specialized fields. However, the quality of the result obtained is greatly dependent on their design and calculation means. To this purpose, the use of modern design methods represents a real amplification of these means.

What Does "New Design Methods" Mean?

Of course, these methods result from the use of computer tools and, first of all, of computer-aided design (CAD). However, we can not pass over the methods based on logic analysis, namely value analysis and failure and reliability analysis. Although these methods make use of computer tools (e.g., for information acquisition and analysis), they have their own character, which consists of implementing working methodologies adapted to the selected target (cost reduction, reliability, and safety).

Contribution of Modern Methods

Contribution to the Geometrical Definition

As mentioned before, the problem to be solved is the adaptation of the landing gear geometry to the aircraft

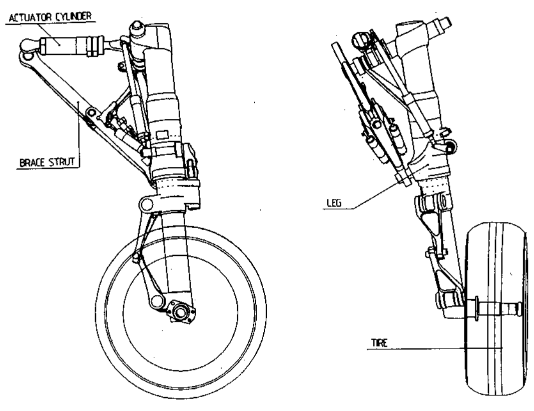

Fig. 1 Rafale main landing gear.

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configuration and structure. The type of tire is selected depending on the weight to be carried. Its down location is chosen in consideration of c.g. location, lateral stability (track selection), and ground clearance requirements. Once these problems are solved, the following points remain to be studied: 1) retracting the wheel housing within the space provided for the landing gear, 2) determining the position of a hinge pin (about which the leg rotates during retraction) and locating the leg attachments on this pin in a solid area of the aircraft, and 3) checking that the tires' retraction path and the space swept by these tires do not result in interferences with the aircraft structure and/or with the external stores (cans or missiles in the case of fighter aircraft).

In order to find the best compromise, it is necessary to proceed by successive iterative steps. The advantage offered by CAD is easy to understand. From the moment a kinematic principle has been selected and entered in the data base, it is possible to modify the geometric parameters as much as is necessary to reach the optimum solution.

Figure 3 shows the final result of a study aimed at determining the hinge pin location of a twin-wheels main landing gear. Sometimes it is necessary to use supplementary kinematics such as shock absorber shortening and/or wheel pivoting on retraction. Figure 4 precisely shows the wheel-pivoting kinematics on retraction of the main landing gear of the Rafale aircraft prototype (already shown in Fig. 1). We can see in Fig. 5 that tire passage between the door and the external store was a hard problem. CAD contribution to the definition of such a kinematics was time-saving, precision, and assurance that the optimum definition was obtained.

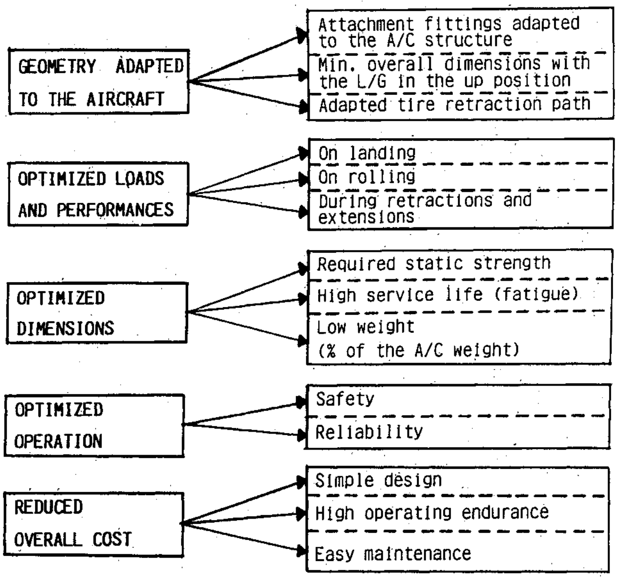

Fig. 2 Challenges of the landing gear.

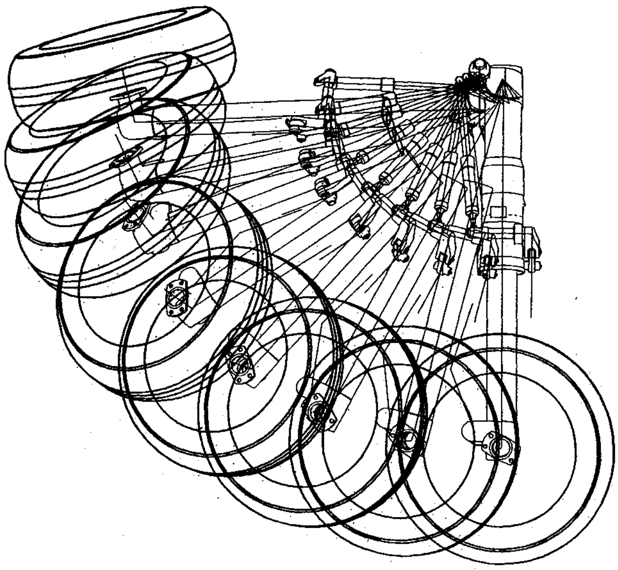

Fig. 4 Rafale main landing gear: wheel pivoting on retraction.

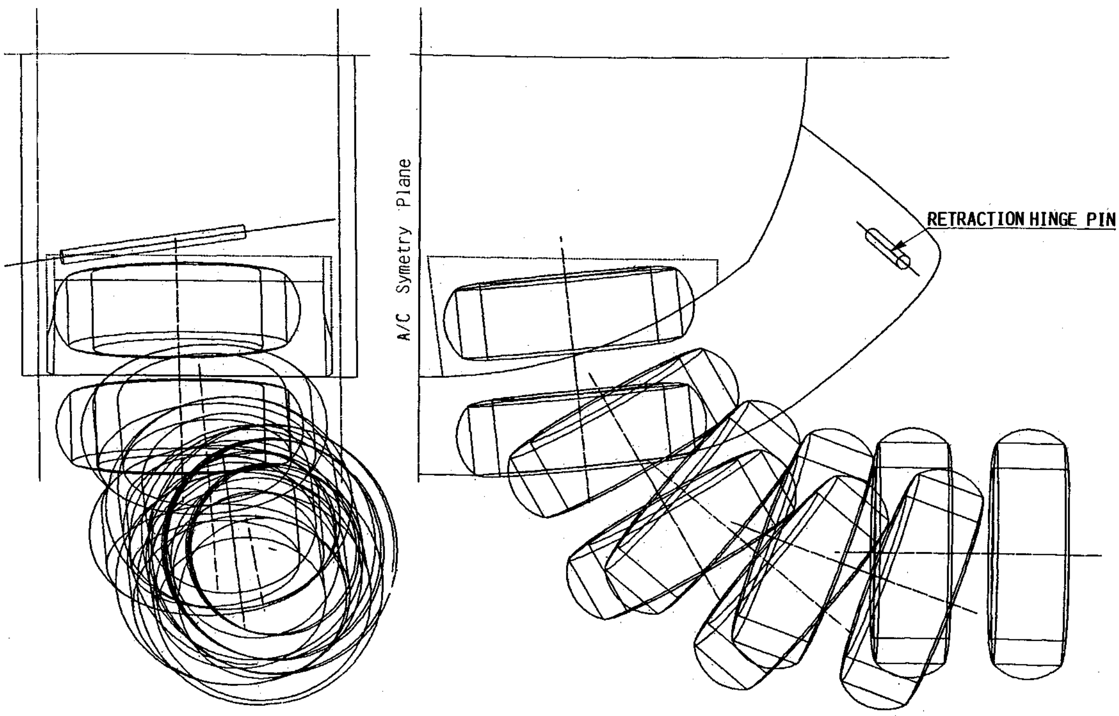

Fig. 3 Main landing gear: retraction hinge pin and volume swept by the tires.

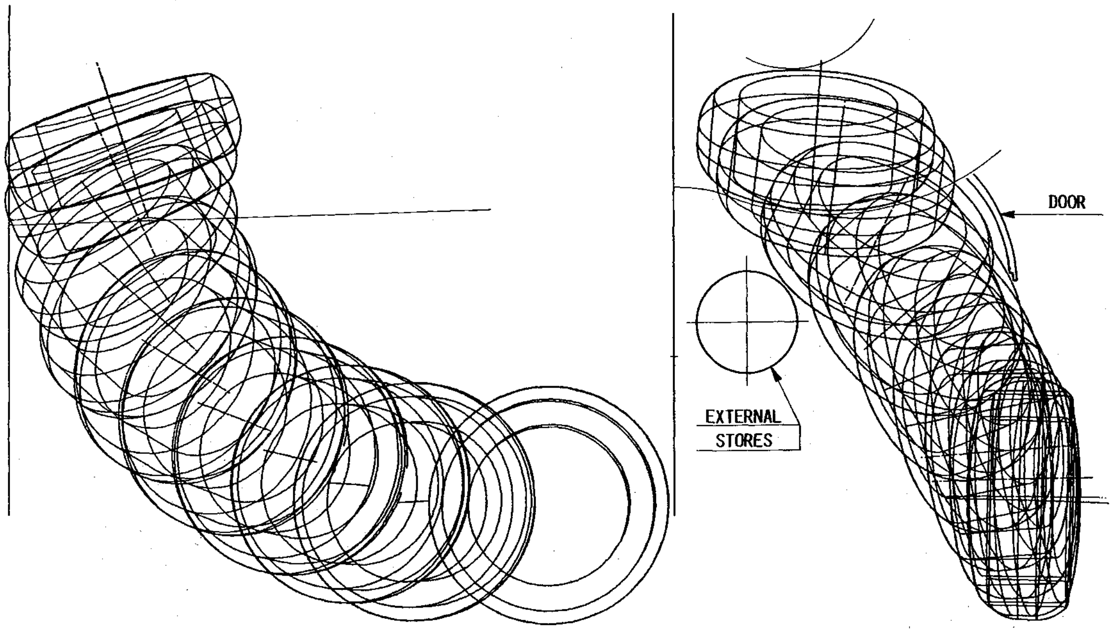

Fig. 5 Rafale main landing gear: volume swept by the tire on retraction.

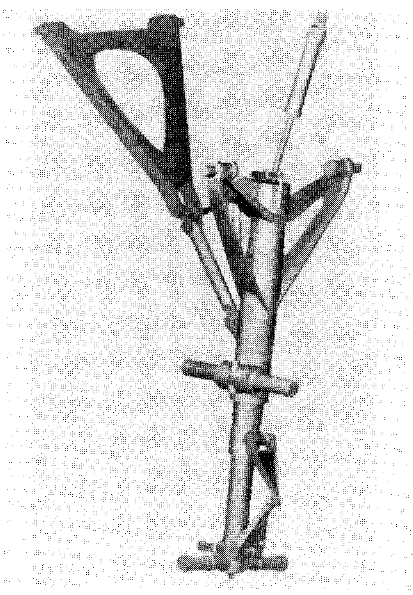

Fig. 6 A 320 Nose landing gear: computer image.

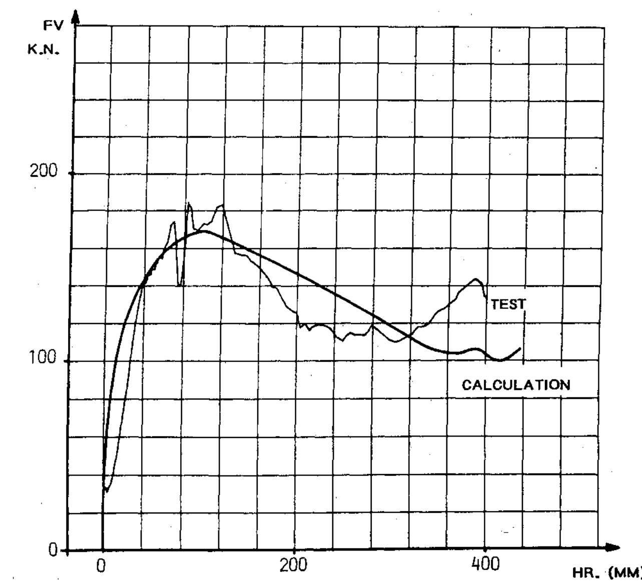

Fig. 7 AS 332 Helicopter main landing gear: crash simulation at 10 m/s.

It is then necessary to determine the geometry connecting the landing gear unit components: leg, brace strut, actuator, and supplementary kinematics, if any. At the same time, it is necessary to define the volumes representing the shape of the parts. This is achieved by using solid modeling interactive software. Thus, we obtain the definition drawing of the complete landing gear (see Fig. 1). The definition drawing can even be completed by a computer image (see example in Fig. 6).

Contribution to Optimization of the Loads and Performances

We find here the application of simulation methods.

On Landing

The load calculation on landing is one of the first tasks in the definition of a landing gear. These loads first depend on the aircraft data (weights, speeds, attitudes) and on the leg geometry (shock absorber stroke), but their optimization is related to that of the internal damping law. Today, we can say that this optimization is found by calculation, as the drop tests carried out in a drop test rig are virtually used only for checking purposes (and for the delivery of the certification as required by the authorities). Figure 7 is an example of shock absorber load/stroke diagram obtained by means of a specific program based on the integration of differential and/or integral equations, some of which are nonlinear equations (damping law is a function of kV^2). This program takes into account the tires, the shock absorber hydraulic fluid compressibility, the frictions, and the landing gear distortion under loads. In Fig. 7, we have also plotted the curve recorded during testing. We can note the very good calculation/test correlation, though the example chosen concerns a particularly difficult application: crash at 10m/s on the AS 332 helicopter main landing gear.

On Ground Riding

Riding comfort has long been considered a minor concern. Nowadays, comfort requirements are more and more stringent and all the more as the operation on damaged or hastily repaired runways is being taken into consideration for new fighter projects.

A ground-riding simulation program that has been adequately developed makes it possible to anticipate aircraft behavior on various runway profiles and also to compare a few types of shock absorbers. Figure 8 shows the results of

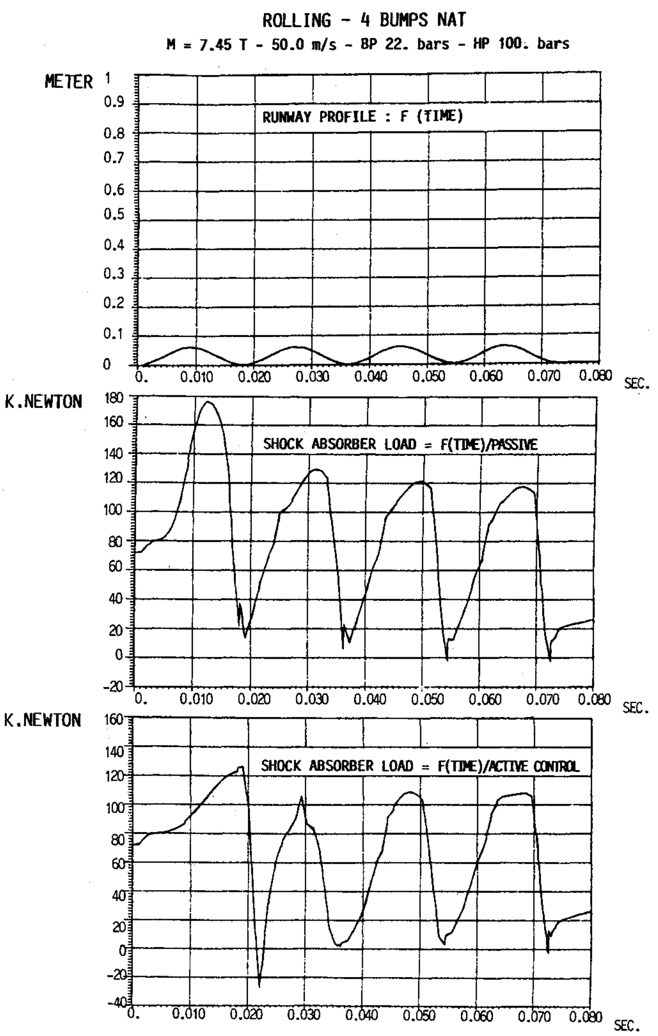

Fig. 8 Mirage 2000 Atterrisseur principal: riding on bad terrain.

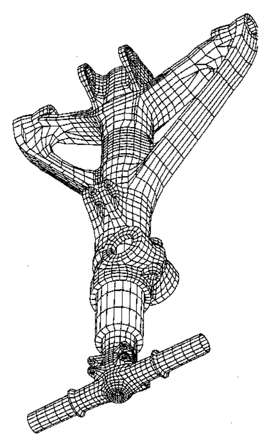

Fig. 9 A 320 Nose landing gear: finite-element analysis (mesh display).

such a simulation devoted to riding on successive 60-mm-high sine shape bumps with two types of shock absorbers: passive (conventional) and adaptive shock absorbers.

Contribution of Modern Methods to the Optimization of Dimensioning (Stress Analysis)

The main structural parts of the landing gear units are characterized by their complex shapes (they are usually three-dimensional parts), several local load applications with three-dimensional loading, stringent overall dimensions and weight requirements, and the use of high-strength materials (such as 35 NCD16 steel heat-treated to 1800 MPa and 300 M steel heat-treated to 1950 MPa, or light alloy 7010 heat-treated to 500 MPa-UTS) whose characteristics involve stringent design rules. All this gives rise to numerous difficult problems. We can say that these problems have only been completely solved since CAD has been used in the design offices, and in particular, since the development of the finite-element analysis methods.

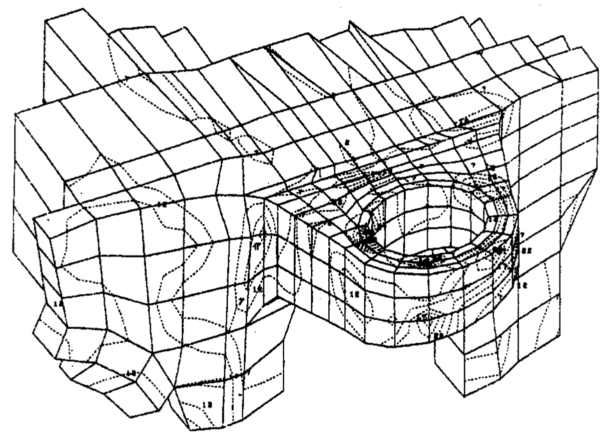

Fig. 10 CN 235 main landing gear: drag brace upper arm; iso stress line plotting.

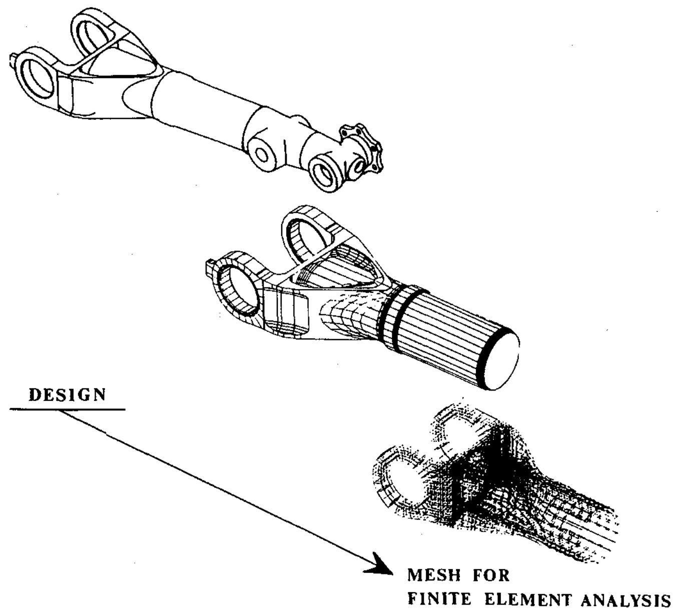

Fig. 11 CN 235 main landing gear: swinging-lever computer-aided design.

Let us consider the parts illustrated in Fig. 9 (the nose landing gear of the A 320). They include many three-dimensional connecting areas between adjacent volumes. In these areas, we often find high-stress gradients, the effect of which, particularly on the fatigue strength, must be carefully examined. A finite-element analysis can determine these stresses with the accuracy required for optimized dimensioning, both from a static and fatigue strength point of view and from a weight point of view.

Such calculations are rather complicated. They often require three-dimensional modeling of 1000–5000 grid points (that is to say 3000–15,000 DOF) which requires a performing calculation code and a powerful computer. However, the progress made over the past few years by using the meshing aid softwares and by the processing and analysis automation (see in Fig. 10 an example of isostress line plotting) made it possible to significantly reduce the calculation time.

From this point of view, the use of CAD in the definition of the part itself, that is to say in the complete and precise three-

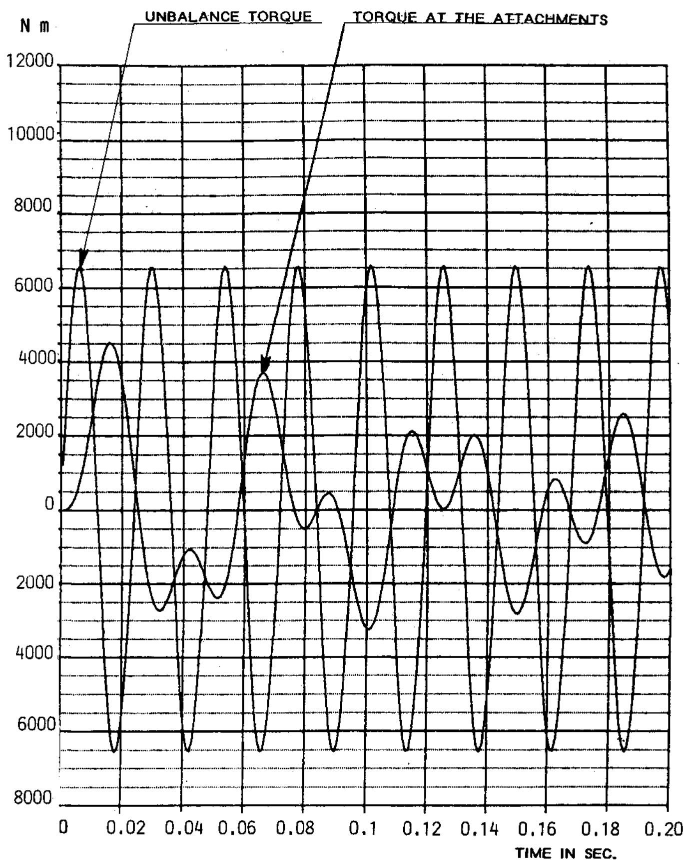

Fig. 12 Simulation of a large tire imbalance on a twin-wheel nose gear.

dimensional definition of its shapes, also constitutes an important step forward. This requires a solid modeling software that makes it possible to define the part from elementary solids placed side by side, common parts being eliminated. The difficulty is to define the connecting areas, with their multiple requirements concerning tangency to the solids. At the present stage, this can be achieved much more easily owing to the integration of a surface modeling software to the solid modeling software.

CAD definition makes meshing much easier. Automated meshing can even be considered, which means a further reduction of the calculation cycle. Figure 11 gives an example of the CAD definition of main landing gear swinging lever hinge lugs with their connections to the tubular part. This area has also been the subject of a meshing, then of a finite-element analysis.

Contribution to Operation Optimization

Contribution to Operation Safety

Let us quote only one example, which is of importance in the case of landing gear: checking that there is no shimmy susceptibility. In the present case, which concerns a twin-wheel landing gear, the problem is to check that the effect of a large imbalance between tires (of the order of 1 kg) is not amplified.

Simulation is based on modeling with beam elements of the landing gear structure (masses and stiffnesses) to which clearances, frictions, and steering control data (including the electronic control network) as well as tire stiffnesses are associated. The result, as illustrated by Fig. 12, shows that there is no amplification of the moment transmitted to the aircraft structure up to the takeoff speed.

Contribution to Operation Reliability

A landing gear incorporates several operational systems. Of course, the operational reliability of each of these systems has

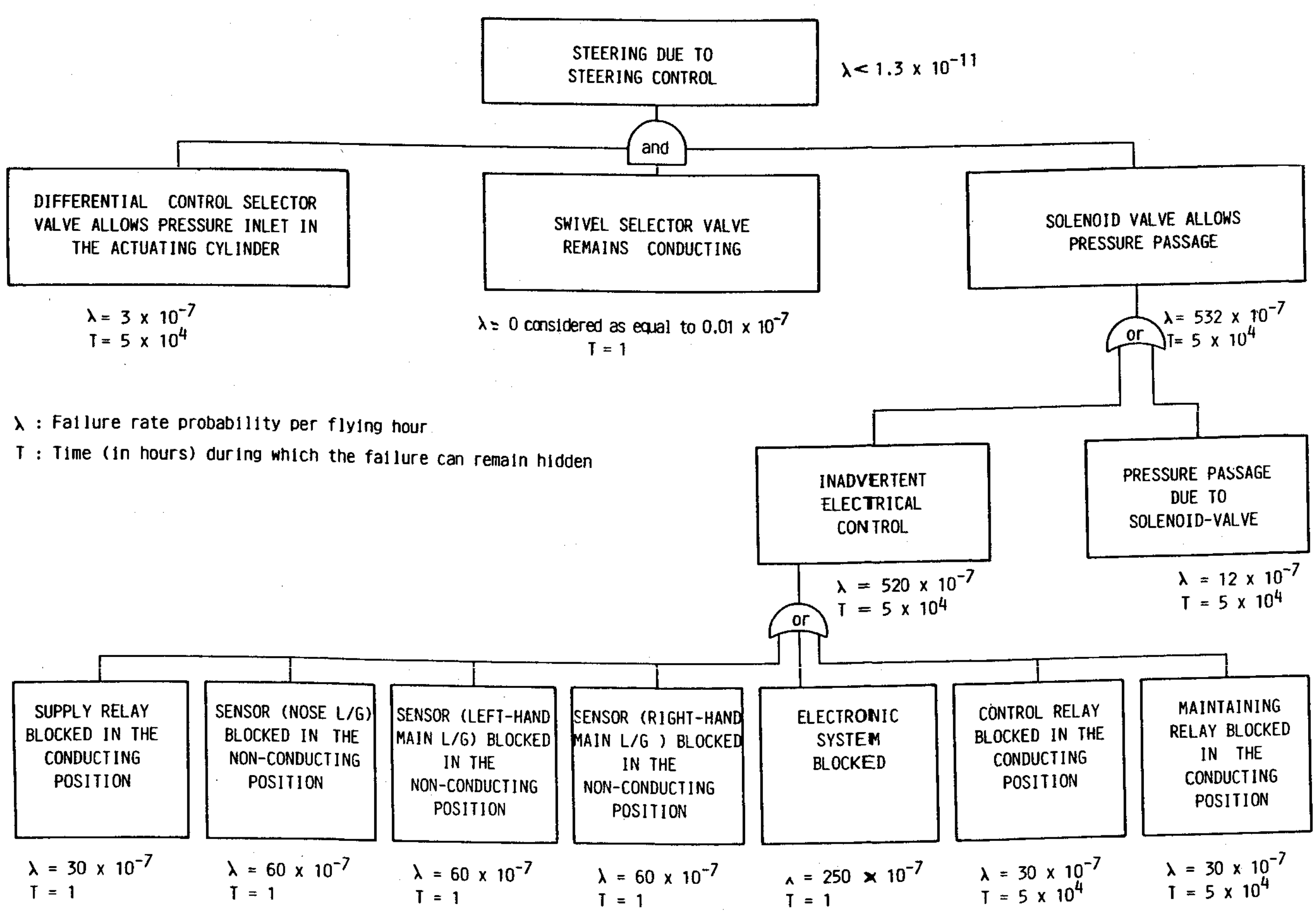

Fig. 13 Inadvertent steering probability A/C in flight: landing gear up.

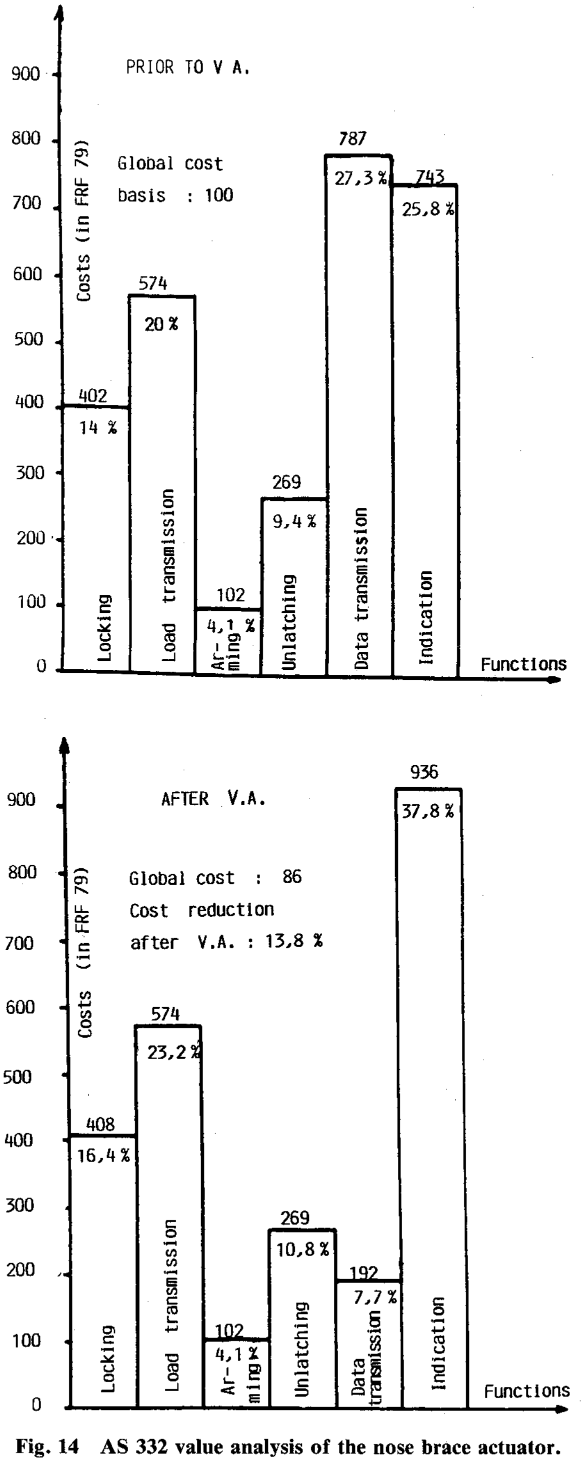

Fig. 14 AS 332 value analysis of the nose brace actuator.

to be studied. This is the purpose of failure and reliability analysis, which consists of a systematic investigation of the effects of the failure of the various functions and of the consequences of all the possible failure combinations within each system. The results of this analysis can be shown in a schematic diagram in the form of a fault-tree analysis. As shown in Fig. 13, it concerns the probability of nose wheel inadvertent steering when the landing gear is retracted. In studying this fault tree, it can be noticed immediately that the probability of the occurrence of such an inadvertent steering is extremely remote. In fact, this type of analysis is considered as a design tool because it allows critical points to be detected. The designer is thus informed of the point to which he must pay special attention. In our example, it can be noted that the determinative fact has been the designer's decision to provide for a hydraulic supply swivel fitting that cuts off the pressure on retraction.

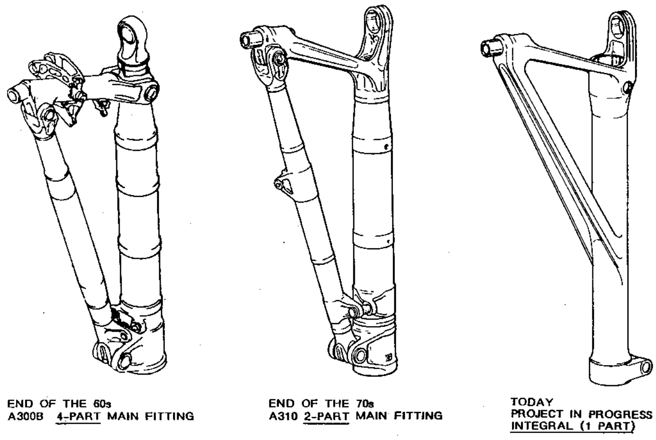

Fig. 15 Design evolution of a wide-body commercial aircraft main landing gear.

Contribution to Overall Cost Reduction (Value Analysis)

It is of no use designing a light, reliable, fatigue-resistant landing gear capable of very high performances if its overall purchase and operation cost is too high. Therefore, if it is necessary to check that each of the assigned objectives has been reached or even slightly exceeded, taking as a basis precise objectives and in particular the technical specifications issued by the aircraft manufacturer, it is also necessary to make sure that the design does not include overly complex arrangements or unnecessary provisions that might go beyond the determined aims.

Value analysis is an aid to carry out such checking. It gives the cost of each function by means of functional diagrams so that the designer is confronted with his responsibility with respect to the choices he makes. Figure 14 shows two examples of functional diagrams, one prior to and the other after the value analysis is carried out on a brace actuator. A comparison between these examples shows that it is possible to reduce the cost by 14% by minimizing the effect of the secondary functions. However, it is to be noted that for the most fundamental choices, i.e., those defining basic geometrical and kinematic principles, a correct value analysis presupposes a close cooperation between the aircraft manufacturer and the landing gear designer.

Consequences

We have tried throughout this paper to show the major consequences of the use of new design methods. Among these major consequences, we can mention the following.

Consequences of the Design Process

A direct time savings is not always easy to figure out but may range from 20–70%, according to the nature of the work. Time saving is, above all, a fluctuating concept, and it keeps increasing as the computer methods (and the level of adaptation of the teams that use said methods) are constantly improving.

Indirect time saving may have various aspects. We will quote two of them, one upstream and the other downstream of the design work:

1) Being in a position to know, very early in the course of the study and with the required accuracy, everything that will be determinative in the landing gear (namely, performances, loads, and stresses) makes it possible to avoid late modifications and then design work wastage.

2) Having a CAD data base makes it possible to signifi-

cantly reduce the time required for the modifications occurring during the life of the product.

Improvement in the quality of the studies results on the one hand from the accuracy achieved (which is precious, particularly for the landing gear kinematics) and on the other hand from the fact that successive iterations for optimum solution research can be made easily.

Capability extension, from the power, reliability, and precision of the performance simulation methods, makes it possible to solve problems better than by (more or less realistic) testings or by turning in-service experience (which is not always easy to quantify) to account.

Consequences on the "Landing Gear" Product

The availability of the new design methods may also be a condition for the selection of a solution. The design of the main parts of landing gears of large dimensions fitted to wide-body commercial aircraft is a typical example.

Figure 15 represents three states of the art of a leg main fitting: assembly of four parts (end of the 60's), assembly of two parts (end of the 70's), and an integral part (today and tomorrow). Of course, the prevailing fact was the development of the manufacturing means (die-forging and three-dimensional machining), but taking into account the economic importance of the aim in view, it is necessary to insure that these parts will meet the fatigue strength and stiffness requirements prior to being launched in manufacture. This is only made possible by a comprehensive and elaborate finite-element analysis.

Another example is the design of future shock absorbers, which will have to be optimized with respect to ground riding (especially on unprepared runways) as well as with respect to landing. The simulation calculations allow the various solutions (namely, adaptative and active control shock absorbers) to be compared in a realistic manner and will show the orientations to be taken and the solutions to be selected, depending on the technological possibilities at that time.