ICAS-86-5.9.1

NEW DESIGN PROCEDURES APPLIED TO LANDING GEAR DEVELOPMENT

Jacques VEAUX
Messier-Hispano-Bugatti, Montrouge, France

Abstract

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 have the overall dimensions as reduced 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 touch-down and to ensure the optimal comfort during rolling.

Last but not the least, landing gear design involves very careful engineering and calculation of the subassembly and of the constituent parts, which must meet the most severe requirements as to safety, reliability, service life, maintainability, while being of course as light and as cost effective as possible.

The purpose of this paper is to point out how much more easily these complex and often contradictory objectives can now be achieved owing to the use of the modern design tools which mainly, but not exclusively, result from the introduction of data processing in the Design and Engineering Departments.

Besides the impact of the use of these methods upon the product itself, that is to say upon the landing gear itself, in the present case, will be emphasized.

We will finish with the foreseeable trends to come in the next future.

1. A few general considerations, as a beginning

1.1. The landing gear functions

We will not waste our time on describing the well known landing gear functions. We can merely say that the landing gear works as an interface between the aircraft and the ground, by transmitting the landing and rolling loads (as well as the parking loads) to the airframe.

Therefore, its primary function is a structural one.

However, as the landing gear is generally retractable, it must ensure the related functions : retraction, extension, up and downlocking as well as the associated indications. Besides, the pilot controlled nose wheel steering is a widespread requirement nowadays.

Consequently, the landing gear is also a multifunction system which involves disciplines as diversified as mechanics, hydraulics, electricity and even electronics.

Anyhow, the landing gear functions are important, since though flying is the primary purpose of an aircraft, the latter spends most of the time on the ground ; above all take-off and landing are among the most critical phases during an aircraft mission.

1.2. Brief terminology

A 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).

As an illustration, *figure 1* represents the main landing gear designed by MESSIER-HISPANO-BUGATTI for the AMD/BA RAFALE prototype aircraft.

1.3. A few general data

The landing gear can carry weights ranging from a few tons to several hundred tons, depending on the aircraft to which it is fitted. However, its own weight accounts only for a very low percentage of the aircraft weight, as shown on the table of *figure 2* (see on following page). This percentage is related to the landing gear geometry (which itself depends on the aircraft configuration) and to the prescribed calculation conditions, in particular the sinking speed on touch-down.

This sinking speed can be included between 3 m/sec (which is the most frequent limit case) and 6 m/sec (landing on aircraft carrier), and even more than 12 m/sec (ultimate case of the helicopter crashworthy landing gears).

FIGURE 1 - RAFALE main landing gear

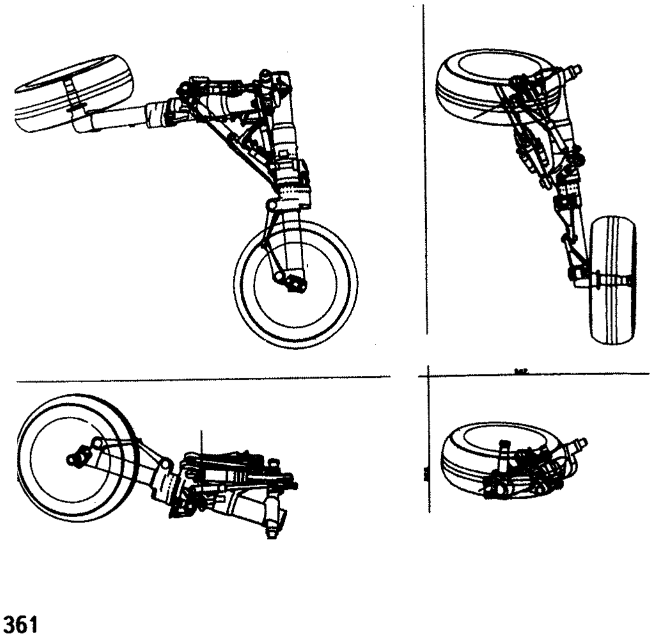


FIGURE 2

LANDING GEAR WEIGHT COMPARISON

AIRCRAFT	1 %	2 m/s	3 m	4	**REMARKS Special characteristics**
ALPHA JET	2.1	2.8	1.184	F	
SUPER-ETENDARD	2.86	5.5	1.327	W	Carrier - based A/C - Main landing gear with shortening on retraction
MIRAGE 2000	1.38	2.8	1.325	W	
JAGUAR	2.08	3.66	1.667	F	Main landing gear with wheel pivoting on retraction
AMX	1.64	3.66	1.312	F	
MIRAGE F1	2.3	2.8	1.500	F	Main landing gear with wheel rotating on retraction
FALCON 900	1.34	3.05	1.369	W	
ATR 42	1.55	3.05	1.369	W	
CN 235	1.77	3.05	1.09	F	"Tandem" main landing gear
A300-600	2.16	3.05	3.859	W	Boggie main landing gear (without structure bar)
A310-200	2.02	3.05	3.698	W	Boggie main landing gear (without structure bar)

1 : % of the structure weight of the 3 landing gear units versus the aircraft take-off weight
2 : Sinking speed at landing
3 : Length of the main landing gear
4 : Type of main landing gear : F.fuselage W. wing

2. The challenges of the landing gear

The landing gear functions are of primary importance, as we have already pointed out. However, the landing gear should perform its work while being as discreet as possible, that is to say, so that it can be (almost) forgotten.

Hence, the challenges to be taken up, as shown on *figure 3*. Challenges, because the requirements to be met are often contradictory constraints. As a matter of fact, it is not always easy to have for example, 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 on 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.

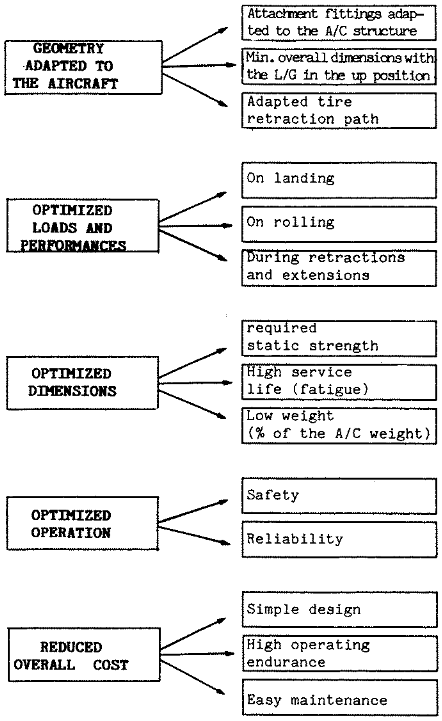


FIGURE 3 - THE CHALLENGES OF THE LANDING GEAR

3. What does "new design methods" mean ?

3.1. Of course, these methods result from the use of computer tools and, first of all, of the CAD (Computer Aided Design). All the same, the expression "Computer Aided Design" must be understood in its broad sense, including the scientific calculation methods.

Apart from Computer Aided Design, which is a design tool, Computer Aided Drafting has been developed. We consider on our part said Computer Aided Drafting as a tool which is related to Computer Aided Design, as solid modeling of the part by Computer Aided Design has to be used for carrying out Computer Aided Drafting.

The Computer Aided Group Technology (CAGT) is also to be taken into account. The Design Offices use it for anteriority or similarity research.

3.2. However, we can't pass over the methods based on logic analysis, namely :

- the value analysis (and its derivations)
- the failure and reliability analysis.

Although some methods make use of computer tools (e.g for informations acquisition and analysis), they however have their own character which consists in implementing working methodologies adapted to the selected target (cost reduction, reliability, safety).

4. The contribution of modern methods

4.1. Contribution to the geometrical definition

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

The type of tire is selected depending on the weight to be taken. Its position is chosen in consideration of C.G. position,lateral stability (track selection) and ground clearance requirements. Once these problems are solved, the following points remain to be studied :

- wheels housing within the space provided for, the landing gear being retracted
- finding 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
- 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 Computer Aided Design is easy to understand. From the moment at which a kinematic principle has been selected and entered in the database, it is possible to modify the geometric parameters as far as is necessary to arrive at the optimum solution.

Figure 4 shows the final result of a study aiming at determining the hinge pin. The study was carried out for a project of a main landing gear fitted with twin wheels (two wheels side by side). Several solutions had been compared prior to selecting the above one, so as to satisfy at best the aircraft manufacturer as to the attachments position.

The problem was comparatively simple here, but it is not always the case. Sometimes, it is necessary to use supplementary kinematics such as shock absorber shortening and/or wheel pivoting on retraction.

Figure 5 precisely shows the wheel pivoting kinematics on retraction of the landing gear of the RAFALE aircraft prototype (already shown on figure 1). We can see on *figure 6* that tire passage between the door and the external store was a delicate problem. The contribution of Computer Aided Design to the definition of such a kinematics can easily be understood: time saving, precision, assurance that this is the optimum definition.

In order that the definition can be completed, it is necessary to determine the geometry connecting the landing gear unit components : leg, brace strut, actuator and supplementary kinematics, if any. This is achieved by plotting the geometrical "skeleton" (see *figure 7* which also concerns the RAFALE main landing gear), then by "wrapping up" this skeleton with volumes representing the shape of the parts. This is achieved by using solid modeling interactive software. We then obtain the definition drawing or project of the complete landing gear (see figure 1). It is to be noted that the work achieved by the project engineer can still be speeded up if the latter can make use of the collection of data-base type volumes.

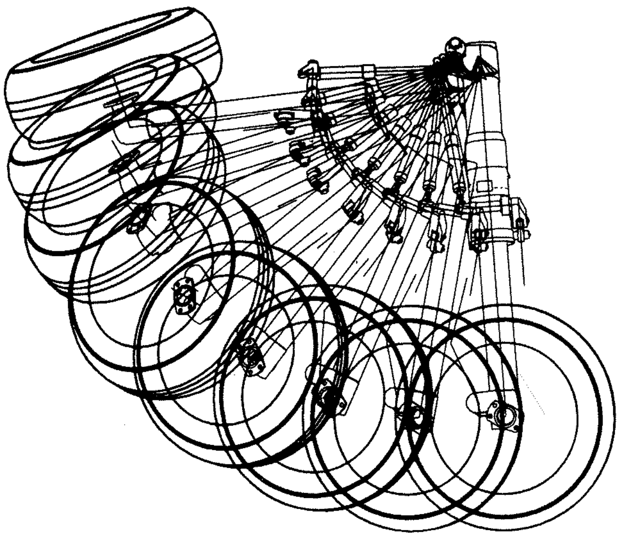


FIGURE 5 - RAFALE MAIN LANDING GEAR WHEEL ROTATION ON RETRACTION

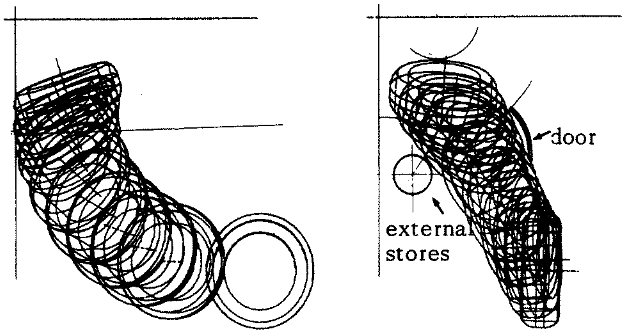


FIGURE 6 - RAFALE MAIN LANDING GEAR WOLUME SWEPT BY THE TIRE ON RETRACTION

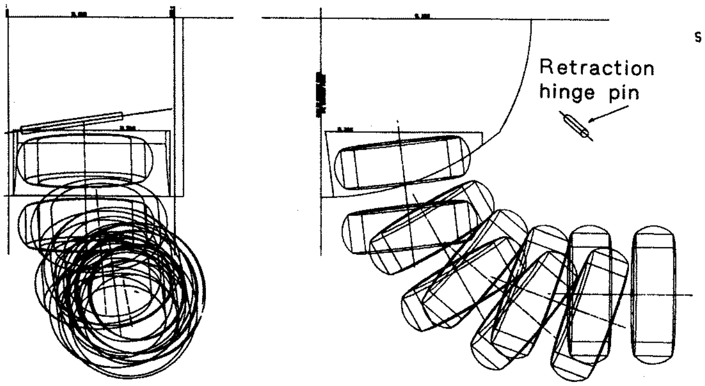


FIGURE 4 - MAIN LANDING GEAR (project) RETRACTION HINGE PIN AND VOLUME SWEPT BY THE TIRES

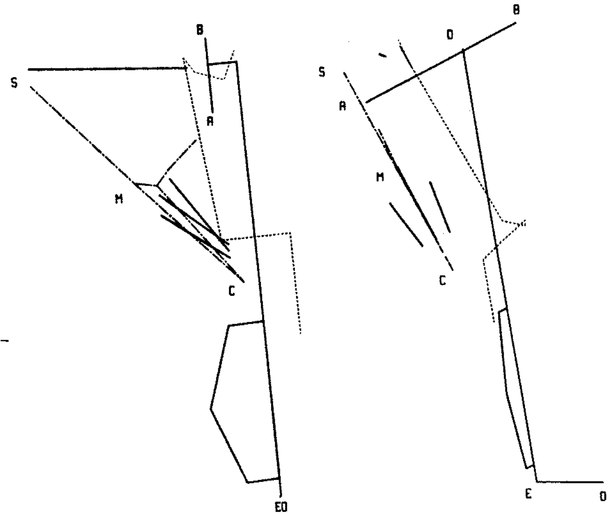


FIGURE 7 - GEOMETRICAL SKELETON RAFALE MAIN LANDING GEAR

The definition drawing can even be completed by a computer image which makes it possible to display the landing gear unit under various angles, and thus to better appreciate the shapes of the component parts (see example on *figure 8*).

4.2. 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 to be achieved in the definition of a landing gear. These loads first depend on the calculation conditions (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 which are carried out on a drop test rig are virtually used only for checking purposes (and for the delivery of the certification as required by the Authorities).

Figure 9 shows an example of shock absorber load/stroke diagram which is obtained by means of a specific program based on the integration of differential and/or integral equations, some of which are non-linear 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. On figure 9, 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/sec on the AS332 helicopter main landing gear.

The accuracy of this tool allows, on the one hand, to foresee the effects of various refinements (damping depending on the stroke, for instance) and, on the other hand, to transmit to the aircraft manufacturer reliable and optimized loads, as early as the beginning of the study.

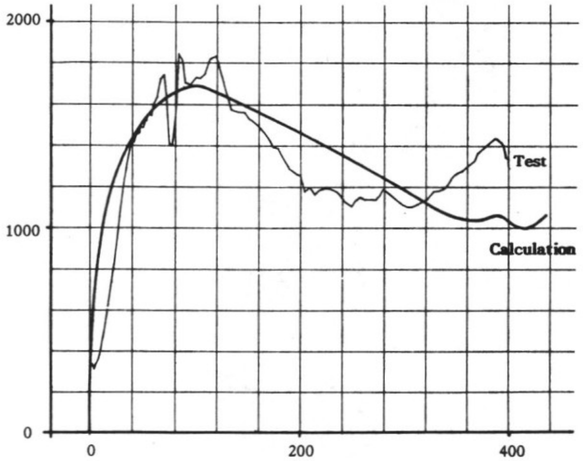


FIGURE 9 - AS332 HELICOPTER
MAIN LANDING GEAR
Crash simulation at 10 m/sec

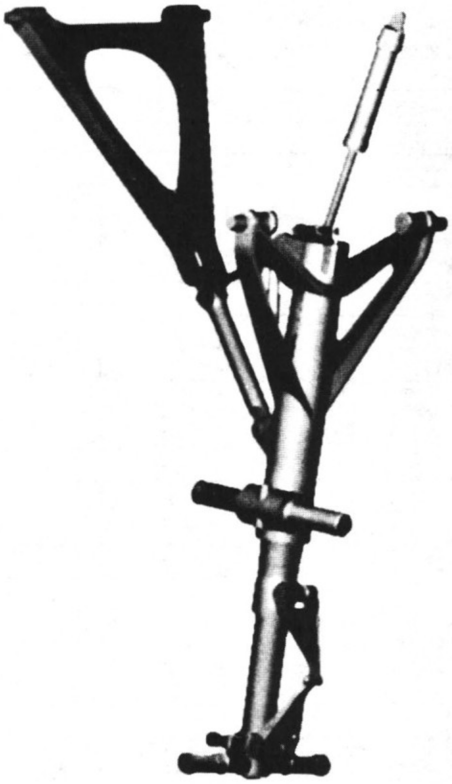


FIGURE 8 - A320 NOSE LANDING GEAR
Computer image

On rolling

Comfort on rolling of the aircraft has long been considered as 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 the new fighter projects.

A rolling simulation program which has been adequately developed makes it possible to predict the aircraft behaviour on various runway profiles and also to compare a few types of shock absorbers. *Figure 10* shows the results of simulation, predicting rolling on successive 60 mm high sine shape bumps with two types of shock absorbers : passive (conventional) and adaptative shock absorbers.

During the retraction - extension actuations

From the very beginning, the actuator intended for landing gear retraction must be correctly dimensioned, which is comparatively easy (and made easier by the use of data processing). In addition, it is necessary to study the dynamic phenomena, in particular on the landing gear units of large dimensions. In effect, the coupling between the moving weight inertia and the actuator hydraulic fluid elasticity leads to pressure peaks which must be evaluated since they may be dimensioning for the actuator and its attachment to the aircraft.

Figure 11 gives the result of such a dynamic calculation of the extension of a main landing gear unit fitted to a wide body commercial aircraft for various speed and load factor conditions (see next page). Measurements carried out on aircraft in flight made it possible to check the accuracy of these calculations.

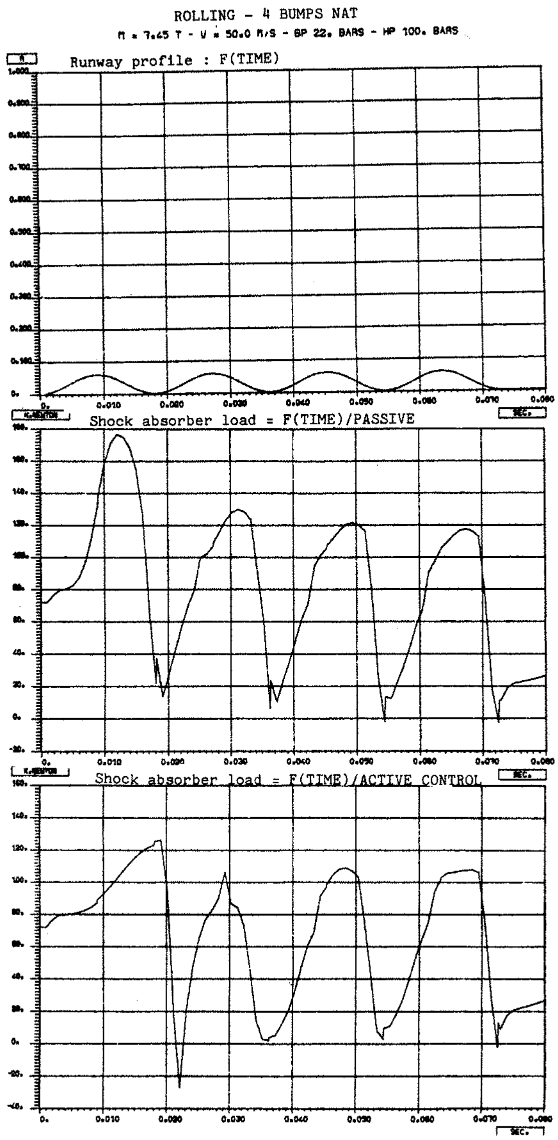


FIGURE 10 - MIRAGE 2000 - MAIN LANDING GEAR ROLLING ON UNPREPARED RUNWAY

4.3. 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 introductions, with a three-dimensional loading
- stringent overall dimensions and weight requirements
- the use of "noble" materials (such as 35NCD16 steel heat treated to 1800 MPa and 300M steel heat treated to 1950 MPa, or light alloy 7010 heat treated to 500 MPa -UTS-) whose high characteristics involve stringent design rules.

All this gives rise to numerous problems which are difficult to solve. We can say that these problems have only been completely solved since Computer Aided Design has been used in the Design Offices, and in particular since the development of the finite elements analysis methods.

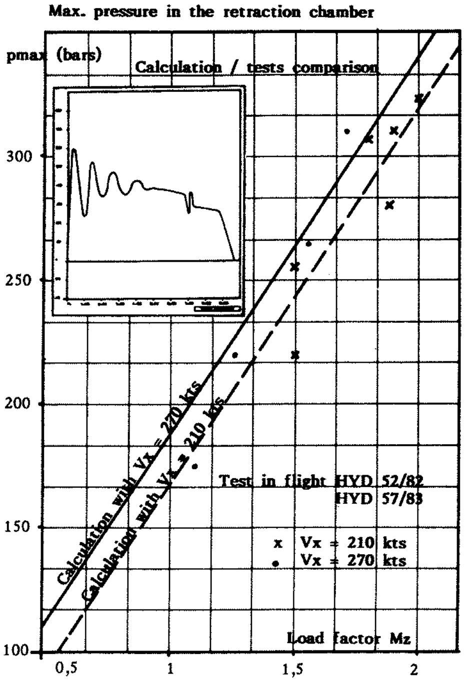


FIGURE 11 - AIRBUS A310 - MAIN LANDING GEAR EXTENSION max. pressure in the actuator

As a matter of fact, let us consider the parts as illustrated on *figure 12* (the nose landing gear of the A320, the latest born aircraft of the AIRBUS INDUSTRIE family shown below). 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.

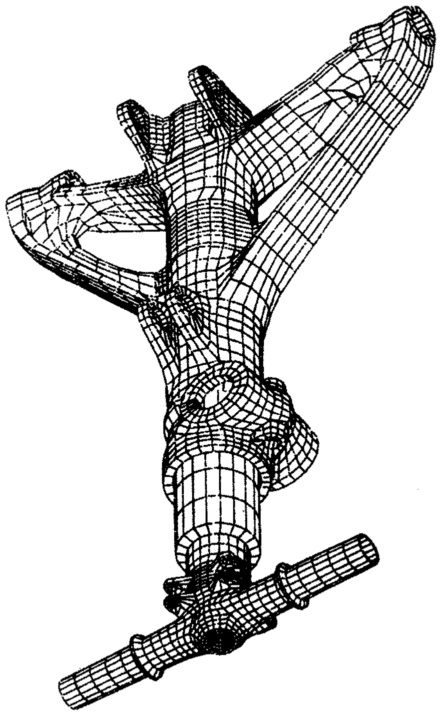


FIGURE 12 - AIRBUS A320 - NOSE LANDING GEAR FINITE ELEMENTS ANALYSIS (mesh display)

A finite elements analysis can determine these stresses with the accuracy required for an optimized dimensioning, both from a (static and fatigue) strength point of view, and from a weight point of view.

We have to concede that unfortunately such calculations are rather heavy and take a long time. This is due to the shape complexity and to the accuracy required in the distorted areas. They result in a three-dimensional medeling having usually 1000 to 5000 grid points (that is to say 3000 to 15000 degrees of freedom), which requires a performing calculation code and powerful computer.

However, it should be noted that the progress made over the past few years, on the one hand, by using the meshing aid softwares and, on the other hand, by the processing and analysis automation (see on *figure 13* an example of iso-stress line plotting) made it possible to significantly reduce the calculation time and, consequently, to get the result earlier and earlier in the design process, that is to say, when definition modifications and comparisons are easier.

Let us mention incidentally that the introduction of composite materials in the landing gear manufacture, which is nowadays limited to probative specimens, will also be based on appropriate calculations made by the Finite Elements method. *Figure 14* gives an example concerning a carbon-epoxy link submitted to tension and compression loads.

To come back to the design process itself, let us say that the real optimization of a structural part definition and dimensioning requires the symbiosis of these two key steps in the design of the part. From this point of view, the use of Computer Aided Design in the definition of the part itself, that is to say in the complete and precise three-dimensional definition of its shapes, constitutes an important step forward.

This requires a solid modeling software which makes it possible to define the part from elementary solids placed side by side, common parts being eliminated. The difficulty is to define the connection areas, which often have evolutive surfaces with 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.

Computer Aided Design definition makes meshing much easier, automation of meshing can even be considered, which means a further reduction of the calculation cycle. Besides, shape modifications or adjustments required to ensure optimization become much easier and much more simple when compared to conventional manual definition.

Figure 15 (see on the following page) gives the example of the Computer Aided Design definition of a 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 Elements analysis.

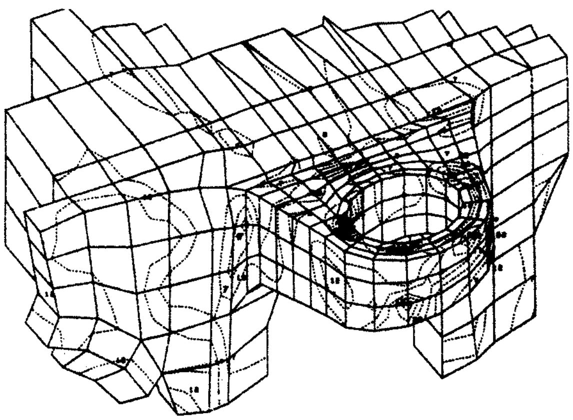


FIGURE 13 - CN235 MAIN LANDING GEAR
Drag brace upper arm
Iso-stress lines plotting

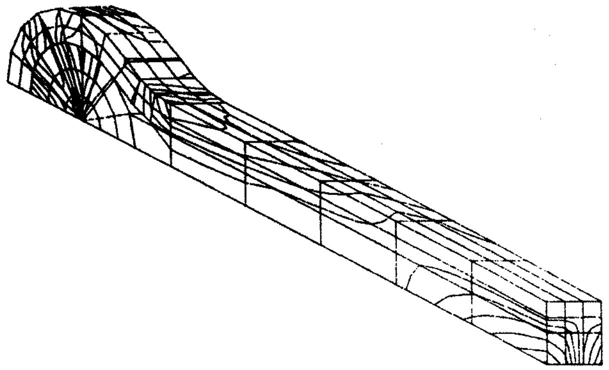


FIGURE 14 - Composite link for landing gear
Three dimensional meshing
Iso-stresses

4.4. Contribution to operation optimization

Contribution to operation safety

Let us quote only one example, which is of importance in the case of a 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 great tire unbalance (of the order of one kg) is not amplified.

Simulation is based on modeling with beam elements of the landing gear structure (masses and stiffnesses) to which clearances, frictions , steering control data -including the electronic control network- as well as tire stiffnesses, are associated.

The result, as illustrated by *figure 16* (see on the following page) shows that there is no amplification of the moment transmitted to the aircraft structure at the take-off speed.

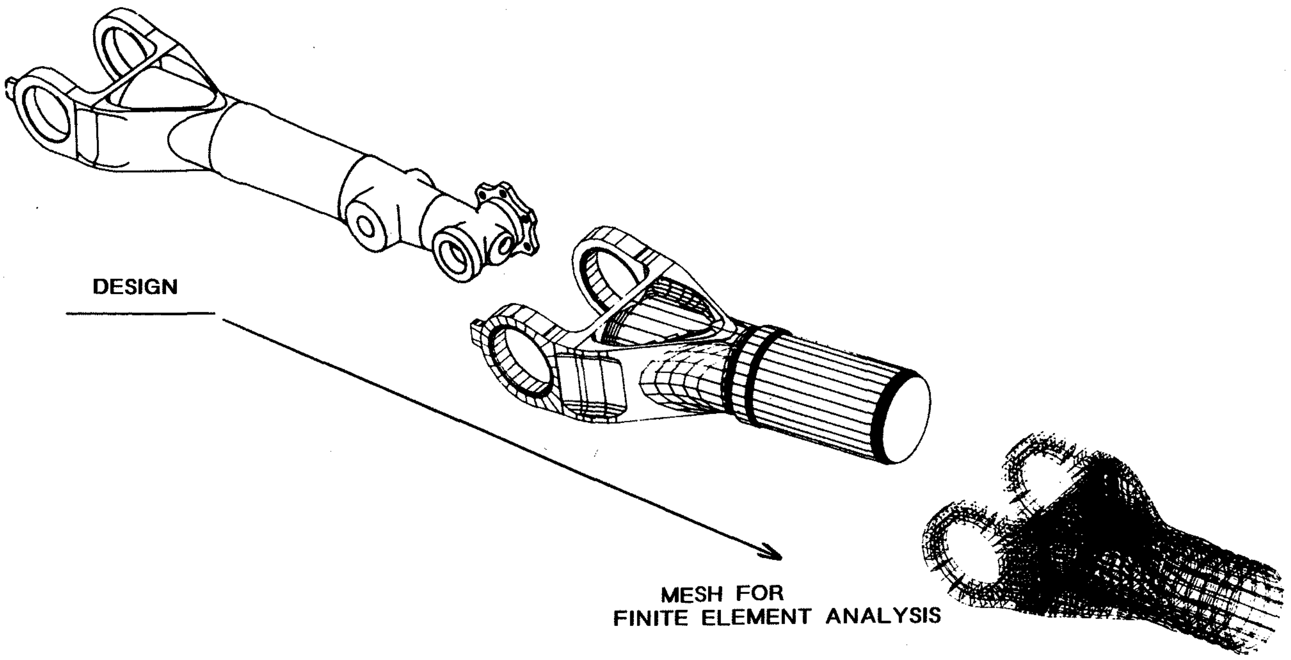


FIGURE 15 - CN235 MAIN LANDING GEAR - SWINGING LEVER COMPUTER AIDED DESIGN

Contribution to operation reliability

A landing gear also incorporates several associated operational systems, as already mentioned in the introduction. Of course, operational reliability of each of these systems has to be studied.

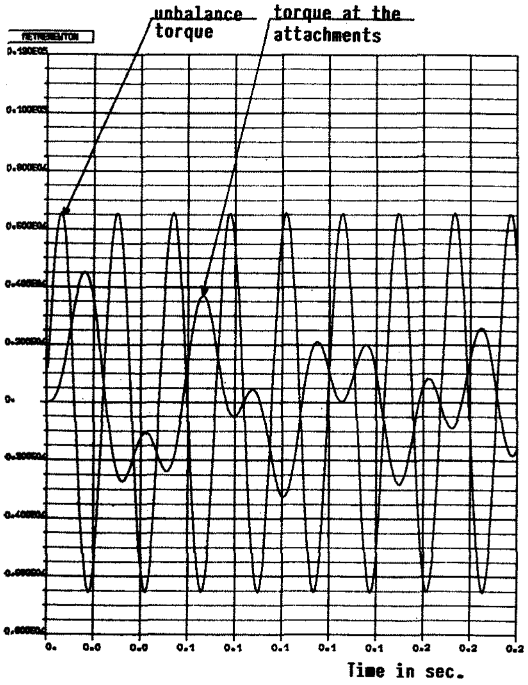


FIGURE 16 - STEERING SIMULATION
Effect of a great tire unbalance on a twin wheel nose gear.

This is the purpose of failure and reliability analyses which consist 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 these analyses can be shown on a schematic diagram, in the form of a fault tree analysis. A fault tree is shown as an example on *figure 17* (see on the following page) : it concerns the probability of nose wheel inadvertent steering with the landing gear retracted. When studying this fault tree, it can be noticed immediately that the probability of occurrence of 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 and, taking as a basis the figures allocated to the failure rates, it points out their relative effects on the system operation. The designer is thus informed of the point to which he must pay special attention in order to meet the reliability objective. 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 which cuts off the pressure on retraction.

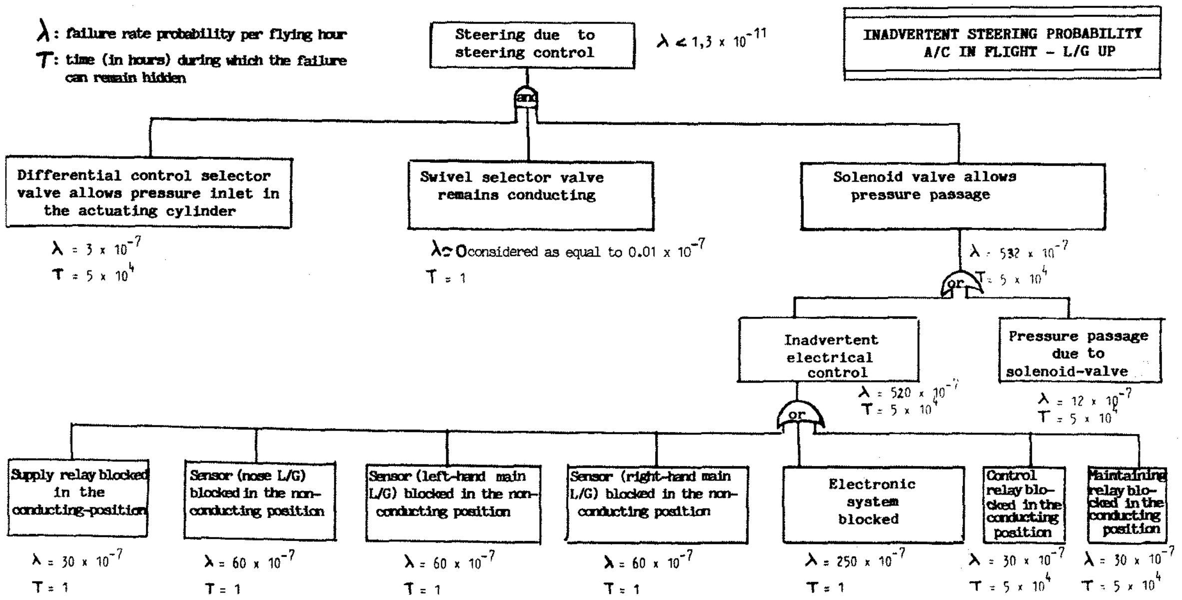
4.5. Contribution to overall cost reduction

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, in particular the Technical Specifications issued by the aircraft manufacturer ; it is also necessary to make sure that the design does not include too complex arrangements or unnecessary provisions which might go beyond the determined aims.

FIGURE 17 - INADVERTENT STEERING PROBABILITY - A/C IN FLIGHT - LANDING GEAR UP



The purpose of Value Analysis and of the derived methods, among which Design to Cost, is precisely to help carry out such checking.

We are not going to dweel too long on these methods, which are dealt with in other specialized publications. We are only going to point out the advantages of applying said methods from the beginning of the landing gear design process. As the matter of fact, Value Analysis 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 18* (below) shows two examples of functional diagrams, one prior to and the other one after the Value Analysis carried out on a brace actuator. A comparison between both examples shows that this has made it 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, that is to say those defining basic geometrical and kinematic principles, a correct value analysis, presupposes a close cooperation between the aircraft manufacturer and the landing gear specialist.

Let us also mention that it is of primary importance that this analysis should take into consideration all the maintainability problems ; in particular, it

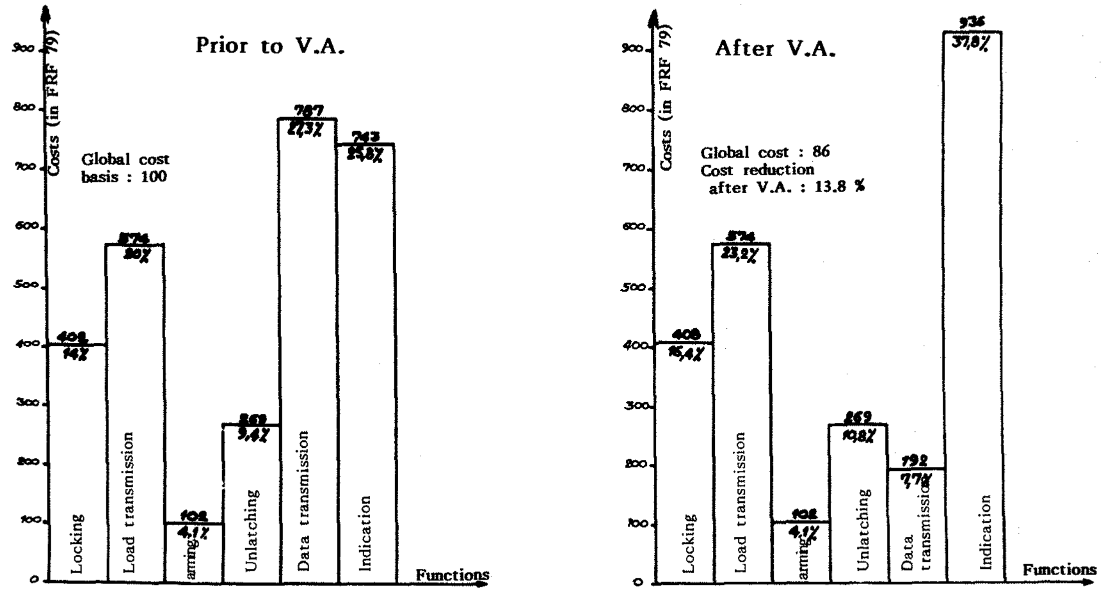


FIGURE 18 - VALUE ANALYSIS - AS 332 - LOCKING, UNLOCKING DEVICES AND INDICATING SYSTEM OF THE NOSE BRACE ACTUATOR (proximity switch version)
Representation of the cost levels corresponding to each function

should include checking that the product maintenance will be easy and that said product service life between overhauls will be satisfactory.

New tools of optimization of the sets of drawings

Once the general design is established, the next step consists in optimizing the working out phase of the detailed drawings. Said detail drawings are to constitute the manufacturing set of drawings. Optimization has to be achieved in various fields, each of which contributes to the cost reduction of the equipment concerned, namely :

- time required for working out the drawings,
- quality of the drawings (no errors, consistency with the mechanical assembly concerned),
- systematic search for design simplicity of each part.

What is to be done in order to achieve this end ? There are several answers to this question, namely:

a) Spreading out the use of Computer Aided Drafting by the Engineering Departments. In this respect, it is to be stated precisely that time reduction is not always the first benefit derived from Computer Aided Drafting for parts as specific as those found on landing gears (with only a small percentage of standard parts). However, Computer Aided Drafting makes it possible to achieve a high graphic and design quality as well as to carry out modifications more easily, which, in turn, results in important time saving.
On the other hand, we are of opinion that in order to reap a real benefit from the use of Computer Aided Drafting , the latter must not be considered as a tool which allows the definition of the part by a set of 2D projections, with the related risks of inconsistency ; it must rather be considered that Computer Aided Drafting naturally follows from Computer Aided Design. In order to obtain the projections of the part, the 3D, and preferably volumic, definition of the part must be taken as a basis.

Figure 19 shows an example of Computer Aided Drafting derived from three-dimensional Computer Aided Design definition.

b) Turning previous experience and studies to account. As a principle, this is, of course, only a matter of common sense. However, its implementation is not as easy as it may seem, as there are limits to draughtmen's memory.
Consequently, the use of a design tool such as the **C.A.G.T.** (Computer Aided Group Technology) opens interesting prospects.

Indeed, this technique goes far beyond the field of the Engineering Departments, since it essentially concerns the Methodizing Departments (operation sheet optimization assistance).

Nevertheless, as far as design is concerned, Computer Aided Group Technology is a great help in the systematic search for similar parts, which the designer must take as a basis so as to apply the same design principles.

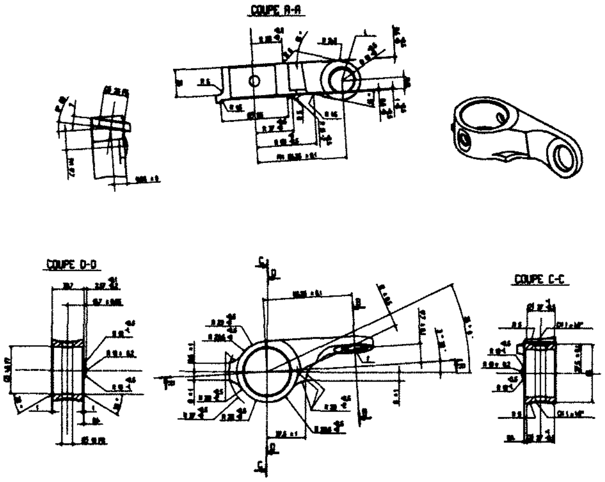


FIGURE 19 - COMPUTER AIDED DRAFTING EXAMPLE

The repercussions are as follows : time saving and the possibility to optimize the parts which are of the same type. On the other hand, the investment corresponds to the codification of the parts from the beginning, which requires a specific organization with a team of specialists in codification settled in the Design and Engineering Departments.

Figure 20 shows a simplified diagram of such a process. One of the results of said Computer Aided Group Technology which is perhaps the most beneficial of all, is **type drawing**, which concerns the same family of parts and is used as a basis for design, quotation, tolerances, materials and processes.

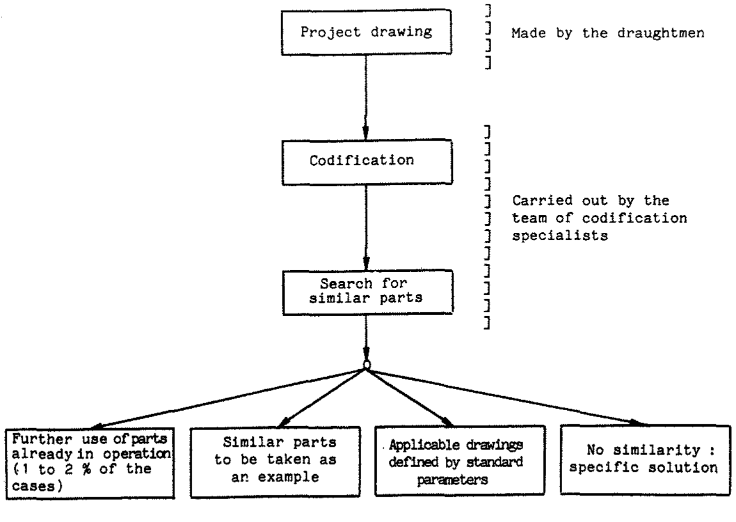


FIGURE 20 - COMPUTER AIDED GROUP TECHNOLOGY PROCESS IN DESIGN OFFICES

5. Consequences

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

5.1. Consequences on the design process

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

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

- being in a position to know, very early in the course of the study and with the required accuracy, everything which will be determinative of the landing gear (namely performances, loads, stresses), makes it possible to avoid late modifications or adaptations likely to bring part of the study hours spent to naught,
- having a Computer Aided Drafting database makes it possible to significantly reduce the time required for the modifications occurring during the life of the product.

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

Extension of the capacity, for instance, due to the power, the reliability and the precision of the performances simulation methods which makes it possible to deal with and solve problems better than before by (more or less realistic) testings of by turning in-service experience to account (which is not always easy to quantify). However, it is necessary to restrain the increasing demande, otherwise the anticipated time saving benefit may be lost.

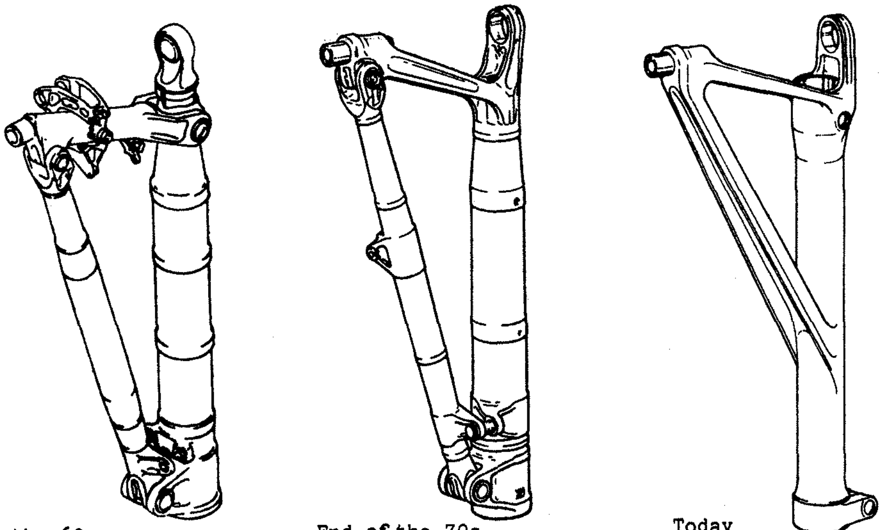
5.2. Consequences on the "landing gear" product

It is obvious that these methods converge to the optimization of the product, both with regard to performances and cost, by the optimization of the product technical definition. The impact of these methods is even greater in some cases in which they represent 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 first typical example.
Figure 21 represents 3 states of the art of a leg main fitting : assembly of **4** parts (end of the 60s), assembly of **2** parts (end of the 70s), integral part (today and tomorrow). Of course, the prevailing fact was the development of the manufacturing means (die-forging and three-dimnesional machining) but taking into account the economic importance of the end in view, it is necessary to make sure that these parts will meet the fatigue strength and the stiffness requirements prior to lauching them in manufacture. This is only made possible by making 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 rolling (especially on unprepared runways) as well as with respect to landing. The specialized Engineering and Design Departments therefore have advanced shock absorber projects ready among their drawings, namely "adaptive" or active-control projects (stiffness and/or damping adjusted or controlled by means of a computer).
The simulation calculations allow the various solutions to be compared in a realistic manner. In fact, from the mission assigned to the aircraft and therefore to the landing gear, these simulations firstly will show the orientations to be taken, and secondly, they will determine the solution to be selected depending on the technological possibilities at that time.

FIGURE 21 - EVOLUTION OF THE DESIGN OF A MAIN LANDING GEAR MAIN FITTING FITTED TO A WIDE BODY COMMERCIAL AIRCRAFT



End of the 60s
A300B 4-part main fitting

End of the 70s
A310 2-part main fitting

Today
project in progress
Integral (1 part)

6. Foreseeable trends

The following two trends are, at least, foreseeable.

6.1. The first trend applies to design methods based on dataprocessing.

We have already mentioned that the sofwares used must be sufficiently developed so that these methods may be successfully applied to the landing gear. These softwares are :

- interactive software for solid modeling of the mechanical parts together with surface software for definition of the connection areas,
- special software for kinematics study,
- finite elements analysis software capable of dealing with three-dimensional problems.

Moreover, it is advisable to have a wide range of special programs of various sizes which may be more or less complex but which must be suitable for solving specific problems.

These tools must easily communicate with each other, but the quality of the exchanged information must not be affected. As a matter of fact, the objective is to achieve a **design integrated process** which allows each of the necessary tasks to be carried out with the help (if required) of the data gained from the other tasks ; this ensures a greater design homogeneity and further time saving.

In order to facilitate said integration, the trend will now be to apply softwares which will have an even greater power and a wide range of applications, in order to limit the number of special programs. Besides, they shall have interfaces allowing them to communicate with each other and with a Computer Aided Design / Computer Aided Drafting data-bases.

This integration will not be limited to the design process alone but within the field of CAD/CAM (Computer Aided Design and Manufacturing), it will progressively extend to the manufacturing process which will have to connect the Computer Aided Drafting data-base of the part definition and the numerically controlled machine programming. This task integration is illustrated on diagram *figure 22.*

6.2. The other trend will be to use more and more often methods such as the Computer Aided Group Technology and the Value Analysis with a view to achieving the best cost / performance compromise.

FIGURE 22 - COMPUTER AIDED DESIGN / COMPUTER AIDED DRAFTING INTEGRATION EXTENDED TO COMPUTER AIDED DESIGN AND MANUFACTURING