LANDING GEAR INTEGRATION ON A SUPERSONIC TRANSPORT AIRCRAFT

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Abstract

The integration of the landing gear on a supersonic commercial transport aircraft is one of the most important design drivers. The reference aircraft has a max. seat capacity of 250 and a gross weight of more than 300 tons. However, the thickness of the supersonic wing is low and the fuselage diameter is approximately four meters only. Thus, the available space to integrate the landing gear is very limited.

A lot of different landing gear concepts were compared in trade–off studies and analysed with the help of a landing gear installation computer program. The landing gear integration in the airframe of the various solutions was performed by the 3D software CATIA. The combination of the investigated arrangements (e.g. two, three and four post main landing gears), the kinematic concepts and all considered tire sizes sum up to a number of more than 100 landing gear solutions.

To identify the most promising landing gear concept from all discovered solutions, the following criteria were applied:

- Integration capability (airframe compatibility)
- Weight and Cost
- Flotation capability (ACN)
- Ground manoeuvring characteristics
- Maintainability

Other important criteria (e.g. safety and reliability) were considered as well, but it was assumed that they are fulfilled in a similar degree by all solutions.

Introduction

The landing gear is one of the most essential aircraft systems, it is a design driver for the entire aircraft configuration. Looking at the total life cycle of an average aircraft, the landing gear carries the aircraft weight approximately as long as the wing. During the ground operations a rolling distance of some 100,000 kilometres will be accumulated within 20 years. The landing gear is one of the most stressed parts of an airframe and is designed for the full aircraft life cycle. Moreover, the landing gear is an important factor because of its weight and cost contribution to the aircraft systems. There is a great influence to the DOC (Direct Operating Cost) due to the wear parts as brakes and tires of the landing gear.

In some aircraft disciplines the landing gear is not very popular. In the extended position, it spoils the aerodynamic shape of the aircraft. Retracted, it needs quite a lot of internal space. During the flight the landing gear seems to be useless and its dead weight impairs the flight performance. But, in the take–off and landing phase it is indispensable. The inherent landing gear functions (steering, braking) are necessary and important for safe ground operations.

The integration of the landing gear is always a problem for the aircraft configuration. Mainly due to space constraints it is difficult to find a good compromise between aerodynamic performance, system operational requirements and system complexity.

The aerodynamic aspect on a supersonic aircraft is obvious more important than on a subsonic aircraft, therefore the landing gear installation is very sensitive to blisters and fairings.

This paper incorporates an efficient methodology how to find from the total of possible solutions a suitable landing gear concept for this type of aircraft configuration. The following steps have been done:

- Analysis of the requirements and marketing/ customer inputs
- Formulation of a landing gear concept (principles, wheel arrangement)
- Selection of candidate solutions
- Evaluation
- First design proposal

The methodology leads to a first design proposal which can be integrated in the aircraft. The possibility to integrate the proposed solution will be analytically proven by using the CATIA 3D tool. If no significant integration problems occur, this proposal could be used as a baseline concept for the aircraft.

Requirements

The projected aircraft is a supersonic commercial transport aircraft with a cruise speed of Mach 2. The reference aircraft has a projected range of 5500 n.mi. with a potential to 6500 n.mi. This range and the seat capacity of 250 passengers lead to a Maximum Take–Off Weight (MTOW) of approximately 300 tons. The aircraft systems shall be in compliance with the latest issue of the JAR 25 certification requirements.

Operational Requirements

The aircraft shall be able to operate from all airports which are normally used by wide–body aircraft. The runway loading or respectively the Aircraft Classification Number (ACN) shall not be worse than other aircraft of a comparable weight (e.g. MD11, B777, A340). The expenditure for landing gear maintenance actions shall not exceed the average on wide–body aircraft. In this context, the number of wheels and brakes shall be as small as possible.
Special attention must be paid to the size of the brakes. The braking performance shall not be improved by an additional brake parachute.
The landing gear system shall be in accordance with the IATA airlines landing gear design requirements and maintenance practices.

Installation Problems

The installation of the landing gears on this type of aircraft is more difficult than on other aircraft, because of the worse combination of high weight and narrow space envelope. In other words: "wide–body aircraft" weight combined with "narrow–body aircraft" fuselage cross–section.
The MLG–bay can be either in the wing (e.g. forward retraction) or in the fuselage (sideways retraction). The relatively flat MLG compartment in the wing has a height of only 1100 mm and in the fuselage the max. height is 1500 mm. The accommodation of the retracted MLG requires in the first case a small diameter of the tires and in the second case low width of the tires.

Constraints

Compared with a subsonic transport aircraft, the integration of a landing gear system on a supersonic transport aircraft leads to additional constraints. One of them is the high temperature in the MLG bay due to high airflow friction. The other constraint is coming mainly from the limited MLG stowage volume and related to this is the size of the tires.
The next constraint is the high kinetic energy in the RTO (Rejected Take–Off) case. The size of the brake heat stack must to big enough to absorb this energy and must be small enough to fit inside the wheels.

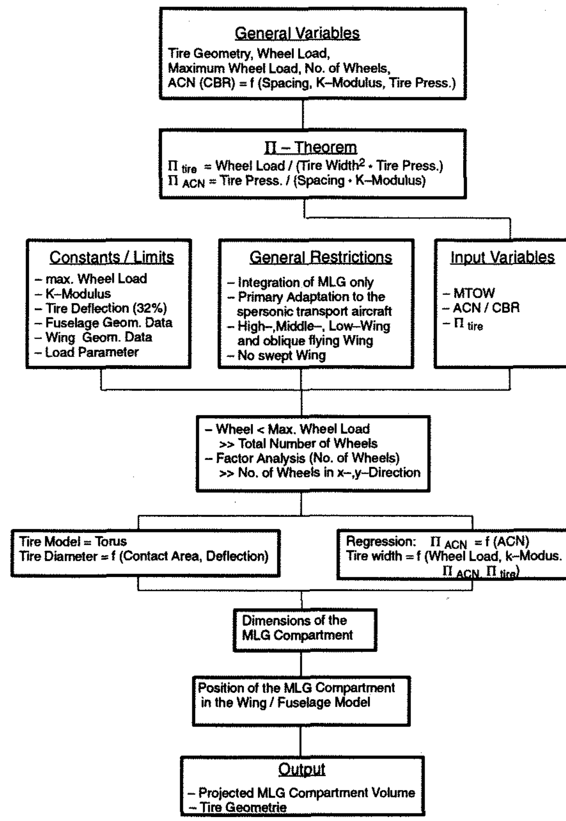

Figure 1 – Data Flow Chart

Concept Development

At the beginning of design process, the first questions are, which kind of "undercarriage" principles for the aircraft have to be considered? What is the best solution to carry the aircraft on ground?

First, there is the well known "Runway–Wheel" system as the most appropriate solution for commercial aircraft operations. This principle is a very practical solution and is used by nearly all land–based fixed–wing aircraft in the world. Exceptions are only a few special/experimental aircraft. Track–type gears and skid/ski–type gears are considered as variations of the "Runway–Wheel" system. Track–type gears can operate at very low ground speeds only. The purpose of the skis is, obviously, to enable operation on snow, but for this aircraft it is not the prime choice. Due to the fact that the supersonic transport aircraft shall be a land–based aircraft, the use of floaters is not considered as well.

Another principle is the "Magnetic Suspension Technique". This technique is already used by high speed trains and has been proven to be reliable. Amongst all of the technical problems, an aircraft application of the "Magnetic Suspension Technique" requires a huge investment in new airport facilities. Because of this fact, such an undercarriage system seems to be not realistic.

The second alternative principle under consideration is an "Air–Cushion" system. This type of unconventional undercarriage is dedicated to soft surface operations and has been pioneered by Bell–Textron, USA. A prototype, a small aircraft (LA–4), was operated successfully on soft muddy ground, sand and water. The essential disadvantages of such a solution are:

- the need for continuous power
- the need for separate support when the aircraft is parked
- poor steering capability and directional control
- considerable dust clouds generated
- braking less responsive than wheel brakes
- high wear rate on the trunk (particular on paved surfaces)

The advantages of the "Air–Cushion" system beside the soft surface capability are as follows:

- operations from very soft and rough surfaces, including ice, snow and marsh
- landing in a slewed attitude in a crosswind
- built–in kneeling capability
- using an externally applied force, the aircraft can be moved easily to a desired location
- lighter weight than an equivalent wheeled gear

Taking all these criteria into account, this system seems to be very difficult to be handled in the daily commercial airplane operations. Up to now, all experiments to replace conventional wheeled and strutted landing gear systems have not been successful. Even in the future there is no sign for a reasonable replacement visible. Maybe, an advanced "vertical take–off and landing" transport aircraft which operates from dedicated launching pads does not need a conventional landing gear any more.

Systematic Combination of Principles

The classical tricycle–type landing gear configuration is selected in this study. Evaluating all pro's and con's of the various "undercarriage" principles, the conventional wheeled landing gear is obviously the best compromise.
Other types of conventional wheeled undercarriage layouts are shown in figure 2. The tail wheel and tandem arrangements are considered as not useful for this type of aircraft.

The identification of the optimum wheel arrangement including tire size and number of tires, has been performed with the help of a dedicated software tool. The software (see figure 1) includes an optimization loop and calculates the attachment position and the required volume of the landing gear. The program needs input data like max. aircraft weight, parameters from the stowage volume available, number of main gear struts/wheels and allowable Aircraft Classification Number (ACN). Then it carries–out a proposal for the wheel arrangement as a best guess.

If all conceivable solutions of nose gear, body gear and wing gear wheel arrangements (footprints) are combined, more than 100 wheel arrangements can be obtained easily. Wing and body gear together are called the main landing gear. Quite a lot of them are impractical wheel arrangements.
To limit the number of impractical solutions the following assumption have been made:

- only one nose landing gear type will be considered. It is the single telescopic strut twin wheel type (II.2)
- the combination of the different Main Landing Gear (MLG) footprints will be concentrated on two, three and four post solutions
- the total number of MLG wheels shall be in the range of min. 12 to max. 32 wheels

The most promising solutions are combined only.

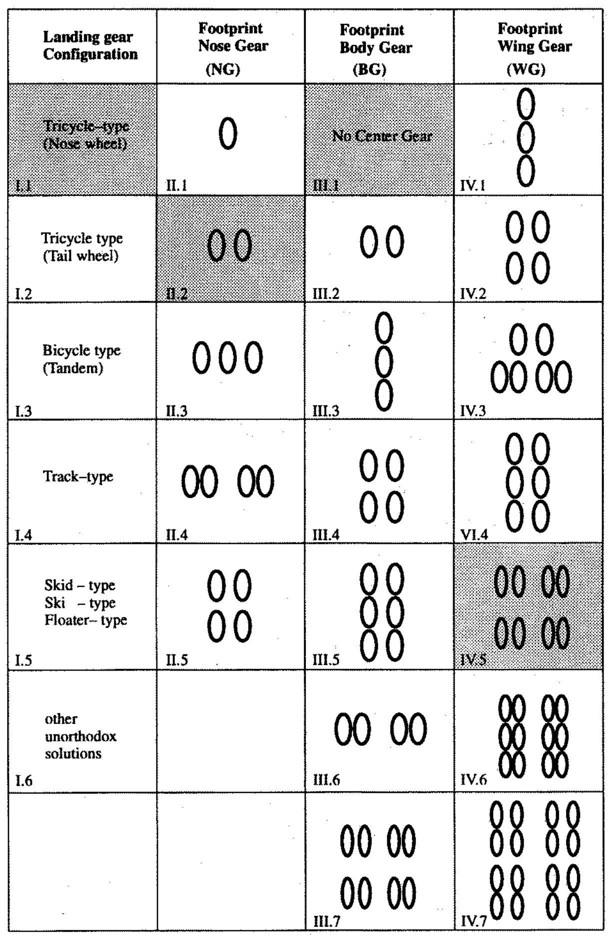

Figure 2 – Landing Gear Layout Matrix (extract).

In figure 2 the footprint of the body and the wing gear is shown for one post only. In the dark back grounded areas is an example of one possible solution.

In this example, the solution is of the normal nose wheel–type arrangement with two wing gears and without any centre or body gears. The nose gear has 2 and the main gear has 16 wheels.

Candidate Solutions

With the help of the landing gear layout matrix and the landing gear integration software program a lot of concepts have been carried–out in the first loop. In a second loop, from the total of the obtained solutions eight very promising concepts have been chosen for the discussion of the pro's and con's and to carry–out an evaluation of concepts.

Remark: If possible, a MLG concept with not more than two post is preferred and the wheel arrangement shall be symmetrical (e.g. a five wheel bogie is not preferred) to the main strut centre–line.

All of the eight solutions are of the configuration type I.1 and have the nose gear concept II.2. Different is only the MLG–concept.
A brief description of the chosen MLG–concepts:
(For the abbreviations, see figure 2)

- 1. two–post, 12 wheels, sideways retraction
  BG III.1 / 2x WG IV.4
- 2. two–post, 16 wheels, vertical retraction
  BG III.1 / 2x WG IV.5
- 3. two–post, 24 wheels, forward retraction
  BG III.1 / 2x WG IV.6
- 4. two–post, 32 wheels, vertical retraction
  BG III.1 / 2x WG IV.7
- 5. three–post, 16 wheels, wing gear: sideways retraction, centre gear: forward retraction
  1x BG III.4 + 2x WG IV.4
- 6. three–post, 20 wheels, wing gear: vertical retraction, centre gear: forward retraction
  1x BG III.4 + 2x WG IV.5
- 7. four–post, 20 wheels, wing gear: sideways retraction, centre gear: forward retraction
  2x BG III.4 + 2x WG IV.4
- 8. four–post, 24 wheels, wing gear: sideways retraction, centre gear: forward retraction
  2x BG III.5 + 2x WG IV.4

These main landing gear concepts are of different strut and wheel arrangements. There are two–post (e.g. A300), three–post (e.g. MD11) and four–post (e.g. B747) main landing gear arrangements and wheel arrangements from 12 to 32 wheels under consideration.

Six arrangements are compatible with the installation constraints in the airframe without significant interference within the space envelope. The solutions 1 and 3 are difficult to install within the space envelope of the airframe, but with additional fairings the integration becomes possible.

First Concepts

It is not possible to show and describe all of the eight solutions very detailed in this paper. But, four of them will be roughly introduced.

The solution 1 (see figure 3) is a sideways retracting two–post MLG with 6 wheels on each bogie. A shortening device is incorporated to keep the installation volume small and one axle of the bogie steerable for ground manoeuvring. This concept is interesting because of the small number of wheels & brakes (maintenance cost).This has an advantage in low weight. But due to the large tire size and the large tire spacing, the retracted MLG needs a minimum stowage compartment height of 2000 mm. In this case a belly fairing of approximately 500 mm height is needed to cover the retracted gear.

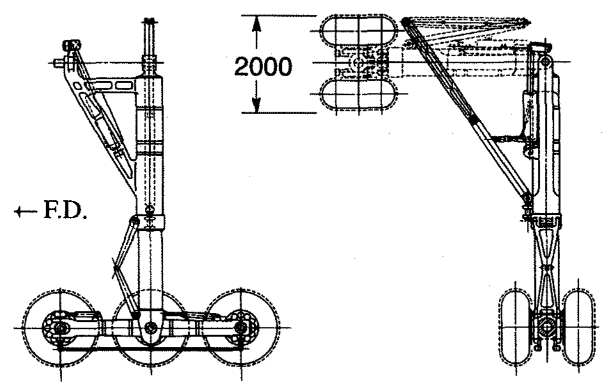

Figure 3 – MLG with 12 wheels (Sol.1)

This large belly–fairing is not acceptable from the aerodynamic point of view.

The solution 3 (see figure 4) is a forward into the wing retracting gear with 24 tires in the double twin arrangement. The flotation capability is good and the other criteria are met sufficiently. Like solution 1 the height of the required MLG compartment in the wing is too big. There are blisters for the tires under the wing necessary which spoil the aerodynamic performance. The kinematics of the gear are very simple. The 90 deg. forward retractable gear does not need a shortening device.

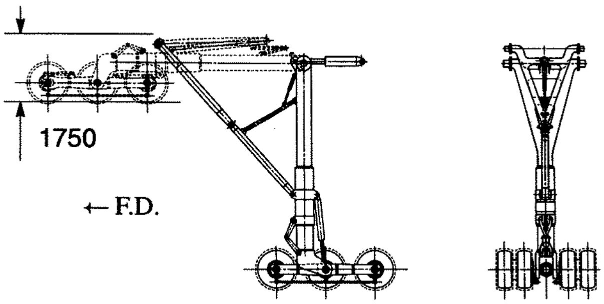

Figure 4 – MLG with 24 wheels (Sol. 3)

The forward retraction of the MLG causes an unwanted movement of the aircraft centre–of–gravity. If this centre–of–gravity movement penalizes the aircraft handling, all effort should be done to keep this impact in certain limits. For this reason sideways or vertically retractable main landing gears are more in favour.
Except the preferred two–post solutions there are three– and four–post solutions considered as well. For example the solution 7 (see figure 5) with a 20 wheel arrangement is quite well to integrate into the MLG compartments in both fuselage and wing. The flotation capability is good, ground manoeuvring and maintainability aspects are met. The criteria "weight and cost" are penalizing this MLG concept. The four–post MLG concept is obviously a greater weight and cost driver than a relatively simple two–post solution. The 20 wheel solution 7 consists of two forward retracting 4 wheel bogie body gears and two sideways retracting 6 wheel bogie wing gears. The wing gears are equipped with a shortening device like solution 1.

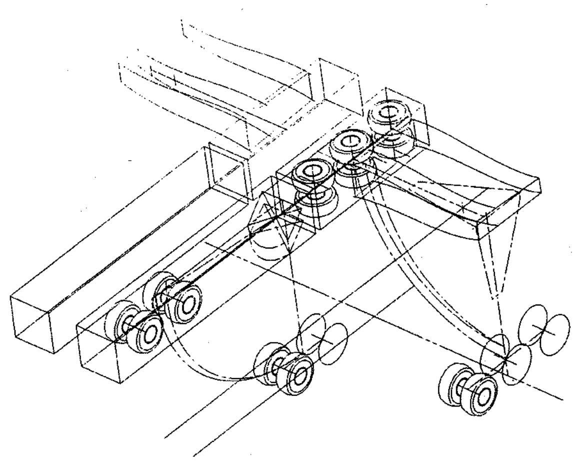

Figure 5 – MLG with 20 wheels (Sol. 7) CATIA 3D integration study

The integration of a simple two–post MLG seems to be very difficult, due to the space constraints in the MLG compartment. To solve this problem a new kinematics concept is required. The aim is to keep the height of the retracted gear low (not more than 1000 mm). If possible the height of the retracted gear structure (struts and rods) should not be more than the diameter of the tires.

Evaluation

The evaluation of the eight concepts shall be made with the help of an evaluation matrix (see figure 6). The evaluation matrix applied considers five not rated criteria.

The criteria are:

- Stowage volume demand (Integrateability)
- Weight and Cost
- Flotation (ACN)
- Ground manoeuvrability
- System Complexity

With these criteria the eight solutions are compared and a first selection has been made.

	Integrate–ability	Cost & Weight	Flotation (ACN)	Ground Manoeuv.	Maintain–ability
Sol.1	–	+	o	o	+
Sol.2	+	+	+	+	+
Sol.3	–	o	+	o	o
Sol.4	+	–	+	–	–
Sol.5	o	o	+	o	o
Sol.6	+	o	+	+	o
Sol.7	+	–	+	o	o
Sol.8	+	–	+	–	–

+ = good o = average – = poor

Figure 6 – Evaluation Matrix (simplified)

As indicated from the matrix above the second solution is the best candidate in this comparison. To verify this concept, a more detailed investigation is necessary to identify possible weak points and to ensure the installation within the available space in the airframe.

Design Proposal

In most of the supersonic transport aircraft studies the main landing gear concepts are of the three– or four–post solutions. These concepts permit to install a great number of small wheels and to get good accessibility to all wheels and brakes for maintenance actions.

A great challenge now is the development of a two post MLG concept which is able to carry a lot of small wheels as well. A good ground manoeuvring performance, easy maintenance and less system complexity is required too.

As a first approach the landing gear solution 2 with 16 wheels has been selected for the supersonic transport aircraft as the most competitive concept.

Technical Description

The landing gear consists of a twin wheel nose landing gear (see figure 7) and a two–post 16 wheel main landing gear (see figure 8). The NLG retracts forward into the fuselage and the MLG retracts vertically into the wing. The telescopic–type nose gear is equipped with a steering device for directional control. The NLG tires are of the size 47x15.75–22. The tire spacing on the nose gear is limited to 850 mm to retract the gear in the thin nose section of the aircraft.

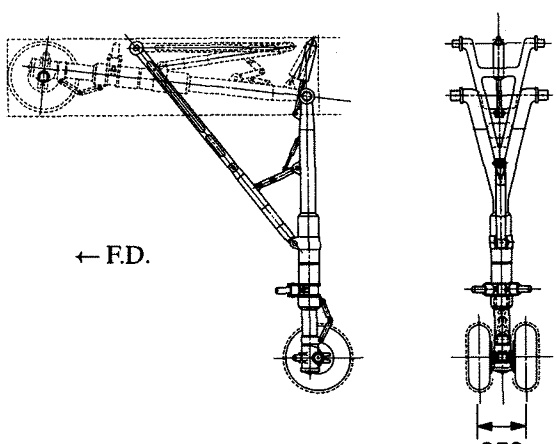

Figure 7 – NLG, twin wheel arrangement

The lower part of the MLG main fitting incorporates the shock absorber and is connected by a hinge joint to the fork–type upper part. The upper part of the main fitting is attached to the wing. These kinematics allow a nearly vertical retraction movement (see figure 9) of the bogie beam. A shortening device of the MLG is not necessary. The main landing gear incorporates 16 multi disk carbon brakes controlled by an anti–skid braking system. The tires of the MLG are of the low aspect ratio–type to get a large ground contact area with this small tire diameter. This type of tire is a new development and not an "off–the–shelf" part. The size of the tires shall be 38x20–18 with an aspect ratio of 0.5

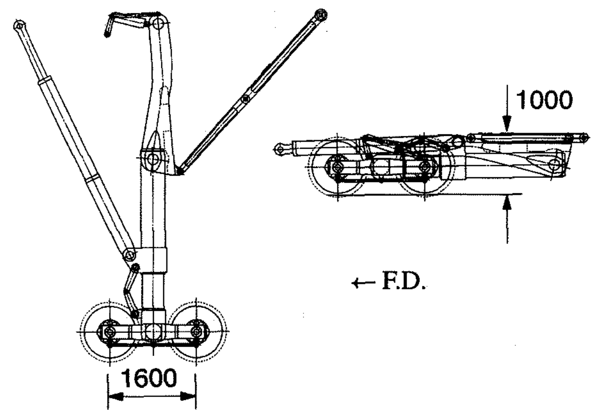

Figure 8 – MLG with 16 wheels (Sol.2)

The MLG arrangement is not equipped with any kind of steering devices. The short axle pitch of 1600 mm ensures a good turning capability with low tire wear. The main landing gear retracts more or less vertically into the wing and requires a minimum of installation volume. Due to the available space in the MLG bay, the size of the retraction actuator must be very small. Therefore, the MLG will be retracted by two small synchronized actuators instead of one. The telescopic drag brace is hydraulically actuated to control the retraction movement.

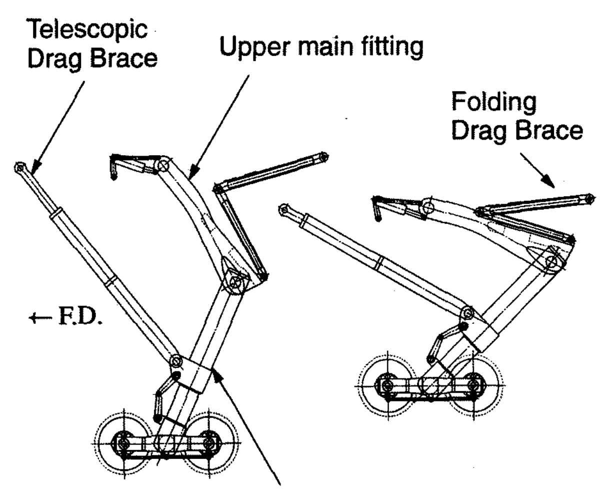

Figure 9 – MLG, 16 wheels (Sol.2) during retraction

The topview of the retracted MLG (see figure 10) shows a H–type bogie beam with 8 independently attached wheels. Compared with a twin tire arrangement like solution 3 this concept has a maintenance advantage.

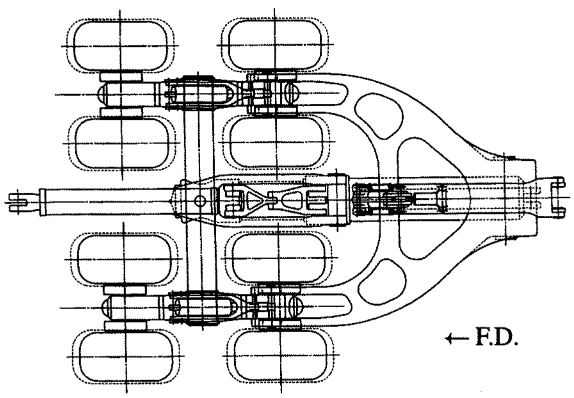

Figure 10 – MLG with 2x8 wheels (Sol.2), topview in the retracted position

Problem Areas

This MLG concept is a good compromise between system complexity and stowage volume.
The concept has not shown serious problems yet. But some of the details must be considered carefully. One of them are the control of two retraction actuators per gear. The installation constraints (height) do not allow the installation of one big retraction actuator instead of two small actuators. The other complicated part is the pitch trimmer of this MLG concept. It has to rotate the bogie beam by 90 deg. during the retraction cycle. The forward drag stay of the MLG should be of the telescopic–type. During the retraction cycle it is necessary to have this element active to control the movement of the gear up to the final position.

The small cross–section of the tires causes a small absolute tire deflection and leads to a relatively stiff tire spring characteristic. Due to this fact, the shock absorber has to counter the problem. Two solutions are considered, one is the double–stage oleo and the other is a semi–actively controlled shock absorber.

Benefits

The selected MLG concept is able to cope with all of the mentioned operational requirements.
The min. height of the necessary installation space is approximately 1000 mm without clearances. The vertical retraction kinematics produces only a small movement of the centre–of–gravity. The folding of the main strut is in the forward direction against the air stream, this ensures good emergency extension capability.
The low aspect ratio tires allow a small diameter with a large ground contact area and a good flotation capability.
The MLG does not need a steering device, because of the short axle pitch. The short distance between forward and rear MLG axle ensures a good turning capability. An additional advantage of the two–post bogie gear concept is the low resistance against the rotation for take–off.
The degree of system complexity is not high. Special features like MLG steering or a shortening mechanism are not necessary. The two–post concept in combination with relatively small number of wheels, brakes and tires is a good approach to keep the maintenance cost low.

Summary

This paper shows a systematical approach to identify a suitable landing gear concept for a supersonic transport aircraft. The work has been carried–out with the help of:

- the systematic combination of principles
- an integration software programme
- computer aided design (CAD)

In this paper only a fraction of the total work is described, but the essential points of the methodology are shown.
By this method, within a relatively short time a big amount of different wheel arrangements could be investigated. These arrangements checked with a dedicated computer programme lead to some candidate solutions.
A stringent selection process leads to first concept as the best solution. Since no major problems were discovered in the detailed analysis, this first concept can be considered as the baseline design proposal for the Supersonic Transport Aircraft.

The main features of this MLG concept are:

- The two parts main fitting allows vertical retraction of the MLG with a very small centre–of–gravity movement
- The height of the retracted gear is not more than the tire diameter and leads to a flat MLG compartment
- The short axle pitch leads to good ground manoeuvrability with low tire wear
- The relatively small number of wheels and brakes produces low maintenance costs

- Since MLG steering device and shortening mechanism are not necessary, the system complexity is low
- A new low aspect ratio tire (38x20–18) with a small diameter and a large ground contact area will offer a good flotation capability

In this study some detail problems of the selected solution are identified as not major, see paragraph "Problem Areas". The evaluation of all disadvantages and advantages of the concept, indicates a good compromise in weight, cost and performance. This main landing gear concept is feasible.

References

[1] Norman S. Currey, Aircraft Landing Gear Design Handbook, AIAA Education Series,1988

[2] Dr. Jan Roskam: Airplane Design, Part IV – Landing Gear Systems Roskam Aviation and Eng. Corp., 1989

[3] S.F. Jenkins: L/G design and development Proceedings of the Institution of Mechnical Engineers, Vol. 203, 1989

[4] Jens Nuppnau, Fahrwerksintegration und Massenabschätzung der Fahrwerksgruppe von Überschallverkehrsflugzeugen Studienarbeit, TU Braunschweig 1994

[5] Burkhard Ohly, Landing Gear Design – Contemporary Views and future Trends IJAS Vol.3, No.1, page 6–10, March 1985

[6] Donald W. Young: Aircraft landing gears: The past, present and future aircraft landing gears, Society of Automotive Engineers, page 179–196, 1986