SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

ARP1598 REV. A

Issued 1985-08
Revised 1997-03
Reaffirmed 2010-06

Superseding ARP1598

Landing Gear System Development Plan

RATIONALE

This document has been reaffirmed to comply with the SAE 5-Year Review policy.

FOREWORD

Changes in the revision are format/editorial only.

INTRODUCTION

The development of a landing gear system for a modern high performance air vehicle is an engineering and development process which covers many months in calendar time and also crosses over many disciplines and abilities. The process is subordinate to and dependent upon the plan for development of the vehicle itself. Good engineering design, analysis, and documentation will generally identify most of the necessary parts of the development process and allow the design team to more effectively perform the task.

The total plan is one which might be prepared by a contractor to describe a development program for a specific aircraft, and be submitted for approval before initiation of the actual work. The plan should be revised and updated at intervals during the development program as influencing factors dictate. A milestone chart should be a part of the plan and should show the interrelationship between phases of the development work to be performed. Design reviews should be identified and scheduled. The progressive design verification process to demonstrate compliance with requirements must be clearly delineated. The overall plan may cover as little time as several months but more probably as much as several years depending upon the complexity of the development and, of course, must fall within the constraints of the prime vehicle development plan.

The development has been divided into six functional/chronological phases although each phase overlaps and affects the others. These general divisions are:

Preliminary Design
Design Integration
Component Development
Subsystem Developmen
t“On Air Vehicle” Development
Landing Gear System - In Service Reliability and Maintainability

Discussion of these six major development phases is given in the following pages.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/ARP1598A

1. SCOPE:

This Aerospace Recommended Practice (ARP) is therefore intended to document the process of landing gear system development. Some of the steps covered are mandatory and others are elective, or dependent upon customer requirements or desires. Economics is a very significant factor and for each analysis or test performed, more confidence and assurance of success is gained, but at a price. Some of the steps are performed as a matter of "good engineering practice" and without special recognition. Others are unique to the particular landing gear system and all together comprise a complete development.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-L-87139

3. PRELIMINARY DESIGN:

The preliminary design stage of an aircraft (and all of the systems which comprise the vehicle) is a process in which the designer strives for the optimum overall arrangement to best meet the designated requirements. Adequate attention must be given the landing gear system at this time to prevent compromises which may eventually result in increased maintenance and reliability requirements, and excess weight. At the conclusion of the Preliminary Design phase the Preliminary Design Review (PDR) should be scheduled.

3.1 Design (Preliminary):

3.1.1 Documentation: In all stages of design, it is of paramount importance to establish the design requirement for the system and to document these requirements. This may be done in the form of a "System Definition Manual," "Basic Data Manual," or any similar form. This documentation, established at this point should be updated as the system design progresses. Initially, requirements only will be shown. Prior to completion of the PDR, the means by which each requirement will be verified, should be identified.

3.1.2 Geometric Arrangement: The geometric arrangement of the landing gear legs, structures, wheel arrangements, and other features which affect the vehicle/ground relationship including shock strut/tire/axle strokes should be established and shown on a layout type drawing. Careful consideration should be given to tip-back angle, turnover angle, center of gravity limits, ground clearance to deflected surfaces, landing attitude limits, and takeoff rotation limits.

3.1.3 Tire/Wheel/Brake Sizing: Selection of tire and wheel size should be made in accordance with best weight and load information available, and revised as required during the P/D phase until concept freeze. This must be done in conjunction with sizing the brake to fit the wheel cavity and meet design deceleration and kinetic energy and durability requirements. In sizing tires, particular attention must be given to ground flotation requirements, peak dynamic taxi and landing loads, and takeoff load-speed-time curves.

3.1.4 (N) (Additional Requirements for Carrier Based Aircraft): The tire/wheel must be selected to be compatible with deck strength, cable crossing, and catapulting.

3.1.5 Ground Flotation: Tire/wheel sizing and arrangement must be selected in a manner compatible with ground flotation requirements for operation of the aircraft. Design studies are required in support of analysis.

3.1.6 Component Sizing: Rough sizing of stock strut piston, cylinder, trunnion, supporting structure, etc., must be made to support stowage space requirements in the vehicle.

3.1.7 Kinematics: Retraction/extension/locking kinematics and configurations must be established to provide the required transition of the gear/wheel/tire assemblies from down and locked position to up and locked position. Compatibility of the system with the A/C structure and other basic features not only in the extreme positions (up locked/down locked) but also in all intermediate positions must be demonstrated. Due consideration should be given to “free-fall” capability of the assemblies in emergency conditions.

3.1.8 Trade-Off Studies: The preliminary design phase is the proper time for determination of basic design concepts. This requires trade-off studies in many cases. Some examples of such studies might include:

a. Configuration trade-offs
b. Brake material - steel, carbon, beryllium, etc.
c. Shock strut material - aluminum, steel, etc.
d. Auxiliary braking methods, i.e., drag chutes, arresting hook, etc.
e. Need for tail bumpers, and other auxiliary installations or devices
f. Anti-skid systems

These studies will provide basic information necessary for performance/configuration definition for the total vehicle. Developing concepts for operation of active landing gear system elements (gear sequence and indication, braking control system, nosewheel steering system, etc.) means to portray them in block diagram and/or logic diagram form.

3.1.9 Concept Freeze: At the end of the preliminary design phase, a basic configuration is determined and frozen. This provides a baseline from which to draw up specifications and initiate design/ analysis of components and installations for the air vehicle and all of its systems.

3.2 Analyses (System and Component):

Initial analyses done in the preliminary design stage will frequently be reiterated and/or updated at subsequent stages of design because of changes which occur until final and complete qualification of components and systems. These initial analyses provide necessary weight (preliminary), volume, and performance data to support the total aircraft development.

3.2.1 Brake Kinetic Energy: Sizing of the tire/wheel/brake package requires a deceleration analysis of the aircraft including effects of aerodynamics, engine thrust, drag chutes, etc., to allocate that portion of the kinetic energy which is absorbed by the brakes. Missions profiles for brake durability analysis needs to be defined early in the design program.

3.2.2 Ground Flotation: Requirements for the aircraft generally specify the types of surfaces (runways, taxiways, etc.) from which it will operate. Analysis to verify this capability is done early, since compliance is determined by basic factors, i.e., aircraft weight, gear location with respect to aircraft center of gravity, tire size/operating pressure, number of tires, spacing of tires and landing gear legs. Changing these sizes at a later date is expensive in both cost and schedule.

3.2.3 Loads Analysis (Preliminary): Landing gear strut reactions, wheel loading, landing impact loads, and a general (but based on preliminary A/C data) loads analysis is necessary to enable publication of a development specification and provide data for on-going design.

3.2.4 Stress Analysis (Preliminary): Adequate stress analysis must be made to insure that rough sizes selected for structural members and components are compatible with each other and with space allocations in the aircraft.

3.2.5 Trade-Off Studies: Analysis should be made to back up any design trade-off studies conducted.

3.2.6 Nose Wheel Steering Power Requirements: Conduct a preliminary analysis to determine power requirement for the nose wheel steering unit, based on the geometric configuration of the A/C, the projected weight, and the desired levels of NW steering performance (steering angle, rate, kinematics, etc.).

3.2.7 Retract/Extend Power Requirements: Conduct a preliminary analysis to define landing gear retract/extend placard speeds to define power requirements and operating times.

3.2.8 Other Analysis: Conduct other pertinent analysis, based on requirements and needs of individual design configuration selected. Some such analysis might include crosswind gear capability, catapulting and holdback systems, unique ground maneuvering requirements, etc.

3.3 Tests (Preliminary Design):

This stage of development of a landing gear system does not generally include a great variety of tests. Some component or model tests are appropriate, however, and are only done in order to save time, money, or problems at a later date.

3.3.1 Kinematics Test: In order to verify kinematic arrangements for landing gear assembly retraction/extension, or mechanism operations, two and/or three dimensional paper/wood/wire models are utilized. The simplest form might be a bent up paper clip to simulate the axle, the strut, and the trunnion, to demonstrate a path of retraction and rough approximations of the extended and stowed positions of the assembly. Two dimensional models of locking mechanisms are widely used. Sometimes 1/4 scale or full scale three dimensional wood/metal models of the complete gear assembly are appropriate to prove the retraction/extension system concept. Today, use of computer graphics is widespread.

3.3.2 Component Tests (Preliminary): Component tests within the preliminary design phase would generally be limited to those tests necessary to validate an assumption made in design or to demonstrate adequacy of currently available hardware for the new design requirements. For example:

a. Limited drop tests on an existing shock strut to new requirements or,

b. Test of an existing tire to new load/speed/time requirements or for abuse loads on unusual conditions (roll over arresting cable, step bumps, etc.).

4. DESIGN INTEGRATION:

Design and integration of the landing gear system into the aircraft involves the several landing gear unique assemblies (nose landing gear, L/H main gear, R/H main gear, tail bumper, wing tip gear, arresting hook, etc.) and all of the aircraft mounted equipment necessary for control and operation of these systems. Indications to the crew of system status is also included as an important part of this subsystem. The preliminary design configuration will be carried forward in this phase to provide a completely integrated landing gear system in the aircraft.

4.1 Design (Installation and Integration):

Major considerations for design in this phase will include structural backup and support for all gear assemblies and mechanisms, electrical and hydraulic services and interfaces, and mechanical services routed through the aircraft such as brake control cables.

4.1.1 Documentation: Update and extension of the system requirements documentation must cover all system design and performance requirements. Integration of the system requires also that all interface requirements be documented. Power requirements (electrical and hydraulic) and structural interfaces, ground support equipment and any services, needs, or requirements from or to any other system of the vehicle must be covered fully.

4.1.2 Trade-Off Studies: Continue to perform trade-off studies to support the system integration with the aircraft and all other systems.

4.1.3 Layout and Design of Landing and Deceleration Systems Installations: Perform layout and design effort as described in the following paragraphs accompanied by all suitable dynamic analyses. At the conclusion of this phase, a Critical Design Review (CDR) should be scheduled.

4.1.4 (N) Additional Requirements for Carrier Based Aircraft: Provide layouts showing the following:

a. The aircraft in relation to static ground line, deck obstacle clearance line, catapulting attitude, arresting attitude, maximum tail down landing attitude, etc.

b. Spotting study showing relative position of aircraft on flight and hanger decks.

c. Catapult arrangement.

d. Arresting arrangement.

4.1.4.1 Main Landing Gear Installation: Provide a design layout type drawing which clearly shows all elements of the MLG installation with relationship to the A/C structure internal and external equipment and stores and to each other. Positive clearances must be shown in both up locked (stowed) position, down locked position, and all intermediate positions and with all extremes of travel for all elements (see MIL-L-87139). Elements shown must include (as applicable); shock strut, bogie beams, axles, wheels, tires, brakes, up lock and up stop systems for gears and doors, down lock systems, and door assemblies with special attention to clearances for gear and door motions when the gear is in transit. Structural interfaces should be defined clearly. Actuating systems for gears and doors, and all locking systems and other mechanisms, such as indication systems, must be shown.

4.1.4.2 Nose Landing Gear Installation: Provide a design layout type drawing in general accordance with description in previous paragraph. Some special considerations for the NLG layout would include steering system components and clearance definition for swiveling nose wheels to doors, structure, and any adjacent components for all operating conditions. (See MIL-L-87139 for clearances.)

4.1.4.3 Nose Wheel Steering System Installation: Provide a design layout type drawing of the NW steering system on the NW strut assembly. Show clearances throughout the range of travel of the system and show position stops provided for the system, and interface with A/C towing provisions.

4.1.4.4 Wheels/Brakes/Tires Installation: Provide a design layout type drawing of the wheels/brakes/tires installed on the shock strut (both nose and main gear) as applicable. Show in detail all interface requirements; structural, mechanical, hydraulic, and electrical. Show locking method for the wheels on the axles. All extremes of motion of the elements relative to one another should be shown based on static, dynamic, and kinematic analyses.

4.1.4.5 Tail Bumper Installation: Provide a design layout type drawing of the tail bumper installation (as applicable). General information and detail should be shown similar to that previously described in “Main Landing Gear Installation” (4.1.4.1).

4.1.4.6 Arresting Hook Installation: Provide a design layout type drawing of the arresting hook installation (as applicable) based on loads and dynamic analyses of the arresting gear.

4.1.4.7 Other Auxiliary Installations: Provide design layout type drawings for other auxiliary landing gear installations. Other installations which might be applicable are:

a. Catapulting equipment installation
b. Holdback equipment installation
c. Wing tip gear installation
d. Jacking, mooring, towing, equipment installation
e. Door system installation
f. Anti-skid system
g. Indication system

4.1.4.8 Hydraulic System Installation: Provide design layout type drawings (as necessary) for hydraulic systems interfaces and/or installations applicable to the landing gear system.

4.1.4.8.1 Hydraulic System Schematics: Provide block diagrams and schematics of the hydraulic system as it interfaces with and operates the landing gear system, components, assemblies, and installations.

4.1.4.9 Electrical System Installation: Provide design layout type drawings (as required) for electrical system interfaces and/or installations applicable to the landing gear system, including switches and indicating systems.

4.1.4.9.1 Electrical System Schematics: Fully develop control logic at this time by providing block diagrams and schematics of the electrical system as it interfaces with and controls operation of the landing gear system components, assemblies, and installations and indicators or switches.

4.1.4.10 Other Design: Provide design layout type drawings for detail design of components and assemblies broken out from installations in all the above noted paragraphs. These layouts should show adequate detail and dimensional data such that they can be utilized for preparation of production drawings.

4.1.5 Preparation and Release of Production and Drawings: Provide all engineering drawings and technical data necessary for fabrication of the landing gear system detail parts, assemblies, components, and installations.

4.1.5.1 Detail Drawings: A detail drawing is defined as one which provides information required for the manufacturing department to produce a single part. These drawings will normally be made prior to assembly and installation type drawings since dimensions on the details are needed to prepare the next higher assembly drawings. In some cases, decisions must be made as to whether the part will be machined from a billet or made from a forging or casting.

4.1.5.1.1 Forging/Casting Drawings: Forging and casting drawings are a particular category of detail drawings. These types of parts generally require longer production times and therefore emphasis must be placed on early detail design and release to manufacturing in order to meet the required manufacturing schedule.

4.1.5.2 Assembly Drawings: An assembly drawing is classified as one which provides information required for the manufacturing department to produce a part or component which consists of two or more detail parts.

4.1.5.3 Installation Drawings: Installation drawings are those which provide the information necessary for installing details and assemblies or components into the aircraft or a major subassembly of the aircraft. This manufacturing step is not possible until all details and assemblies have been completed and all attached accessories have been defined. Therefore, the installation drawings are generally the last drawings to be prepared and released to manufacturing.

4.1.6 Procurement Activities: The production cycle of a landing gear system invariably involves working with suppliers. Their activities must therefore be fitted into system development plan. Some landing gear components which most usually fall into this category include shock strut assemblies, tires, wheels, brakes, steering systems, brake and skid control systems and various actuators, switches, valves, and smaller components.

4.1.6.1 Components and/or Subsystem Specification: The first step related to procurement activities is the preparation of technical specifications which define the required performance and control the design of the component or assembly. Important elements of the specification are controls of form, fit, and function. Design requirements in the specification should be followed by verification by test, inspection, analysis, and/or demonstration as assemblies and subsystems to insure the component will fulfill its intended role in the total landing gear system. Specifications usually will include “Design Specification Control Drawings,” or “envelope” drawings and include limits on volume (including swept volume), mass, power requirements and other critical interface parameters. These procurement specifications will generally be released to several suppliers for bid.

4.1.6.2 Supplier Selection: Selection of a supplier to provide the component is normally based upon a satisfactory response to technical requirements, and his demonstrated ability to design and manufacture the components, to meet quality, schedule, and cost requirements.

4.2 Analysis (Installation and Integration):

The area of analysis for installation and integration includes that which is necessary to insure proper design and positioning of the gear assemblies in the aircraft and integration (mechanical, electrical, hydraulic, etc.) with the aircraft and its other systems. Some pertinent analyses are as follows:

4.2.1 External Loads Analysis: Provide analysis to define all external loads including air loads and inertia effects which are applied to and affect the design of the landing gears. Examples of such loads include gear extended loads reflecting maximum gear extended speed, landing impact loads, rollout loads, taxi loads, turning loads, engine run up loads, tie down/mooring loads, towing loads, catapulting and arresting loads (as applicable) and others as necessary.

4.2.2 Internal Loads Analysis: All loads developed by external and operational load analysis, including landing gear door loads, must be broken down into component loads and carried through the landing gear structure (struts, braces, beams, etc.) to provide the basis for structural analysis of components.

4.2.3 Actuator Load/Stroke Analysis: All actuators of the system must be defined by load/stroke requirements resulting from above stated operational analysis.

4.2.4 Power Requirements Analysis: Provide analysis for definition of all system power requirements.

4.2.4.1 Hydraulic Power Requirements: Pressure/flow requirement must be defined to insure performance and proper integration with the total air vehicle hydraulic system.

4.2.4.2 Electrical Power Requirement: Define all electrical power requirements including heat rejection limits for integration with the total air vehicle electrical generating and distribution system.

4.3 Test (Installation and Integration):

Tests conducted to support the “installation and integration” phase of design are an extension of those done in preliminary design, but prior to complete subsystem tests.

4.3.1 Development Tests: Verification tests are frequently needed to prove design concepts, such as selection of trunnion bearings of structural components. Dynamic models are useful as an aid in finalizing configurations for major installations or subsections of that installation.

4.3.2 Mock-Ups: Full scale mock-ups or simulators are sometimes the best methods of verification of space requirements or for integration of mechanical, electrical, and hydraulic service routing. As production parts are received from vendors, they should be installed and evaluated on the full scale mock-up. System function and compatibility are verified on the mock-up.

4.3.3 Breadboard Tests: The use of breadboard tests is sometimes appropriate for verification of design configuration such as electrical or mechanical control circuits.

5. COMPONENT DEVELOPMENT:

This stage of development is between the preliminary design review and first flight and involves the activities of the airframe manufacturer and component subcontractors.

5.1 Main Landing Gear:

5.1.1 Design: The design definition of the main gear is usually a combined airframe manufacturer and supplier effort. Enough preliminary sizing is conducted by the airframe manufacturer to locate and produce an allowable design envelope. Based on conceptual proposals, etc., the supplier usually decides the internal shock strut details, final materials selection, etc., subject to approval. The mechanisms are sometimes designed and built by the airframe manufacturer.

5.1.2 Analysis: Complete stress and fatigue analyses are provided for each component. Damage tolerances assessment is used in the selection of material and potentially to establish inspection intervals, but to date has not been a firm requirement. Dynamic analysis of shimmy, brake chatter, bogie pitch, etc., is conducted on the assembly. This analysis is conducted by the supplier and/or the airframe manufacturer. Environmental analysis usually is limited to assessment prior to cold temperature testing. Photoelastic stress methods are frequently used to identify stress concentrations and to refine the final designs.

5.1.3 Test: The primary verification tests for the main gear are structural and performance in nature. Static and fatigue tests are conducted to verify safety within the design envelope. These tests are most frequently conducted by the supplier, but they can be included in the tests conducted by the air frame manufacturer. Deflection and spring rate measurements are usually taken while the unit is in the structural jig arrangement. A development unit is jig drop tested to verify the energy absorption characteristics are within the design load limit. Modifications can be made to arrive at the final configuration. Each production unit has a proof pressure test and a leakage test. The basic functions and fit are verified on the system mock-up or the air vehicle. Flight tests verify interchangeability and installation characteristics. Static tests of the complete landing gear are usually conducted by the airframe manufacturer.

5.1.4 (N) Additional Requirements for Carrier Based Aircraft: The whole aircraft is drop tested in lieu of a jig drop test. However, JIG drops can be performed to verify basic performance. Shock absorbers such as those used for arresting hook bounce are tested for energy absorption at various velocities. Catapult hold back bars are tested for release loads and kinetics. The catapult and arresting systems, as a whole, are tested to demonstrate adequate life.

5.2 Wheels and Brakes:

5.2.1 Design: The sizing and layout of the wheel and brake equipment, including the nose wheel, are finalized after preparation of interface control drawings and documentation of all design/ performance requirements. The vendor designs his package within a clearance envelope providing proper interface with structural, hydraulic and electrical connections. Long lead items such as forgings are coordinated early with the airframe manufacturer. Frequently, alternate friction materials are ordered coincident with intended production materials for backup in the development testing.

5.2.2 Analysis: The key brake requirement is the brake energy analysis conducted before the equipment is sized and it is the responsibility of the airframe manufacturer. Usually, this is subject to customer or regulatory agency approval. Loads analysis and environmental analysis are used to finalize design requirements. Reliability, maintainability, stress and interface analyses are conducted by the supplier on the design resulting from the development program. Usually, wheel and brake equipment require a new development program because of weight, interface with structure and actuation systems and advancing state of the art considerations.

5.2.3 Test: Wheel structural integrity tests are conducted by the supplier in the form of static tests to the design envelope identified by the airframe manufacturer and roll tests on a dynamometer to a realistic maneuver and life spectrum. A burst test is conducted and various pressure retention evaluations are scheduled throughout the program. The brake assembly is tested by the supplier to verify energy absorption, durability, torque characteristics, environmental compatibility, interface compatibility, determine operating characteristics and evaluate anti-skid brake control systems compatibility. Special tests of various special features or characteristics may be dictated by the supplier design specification. Minimum levels of performance are established for safety of flight demonstration. Flight tests confirm system compatibility and performance.

5.3 Nose Landing Gear:

5.3.1 Design: The design function for the nose landing gear is basically the same as for the main landing gear. However, the special features such as steering, etc. dictate a more extensive design effort, introducing additional interface requirements. If the unit includes catapult requirements, the interface and design functions become increasingly more complex. Towing accommodations add to the complexity of the nose gear design and dictate compatibility with the ground support equipment.

5.3.2 Analysis: As with the main gear, the supplier shall conduct stress and fatigue analyses. Preliminary photoelastic stress analysis, reliability and maintainability analyses may be performed. Cooperatively, the airframe manufacturer and supplier will conduct measurements of deflection and spring rates which will be major contributions for the shimmy analysis. Damage tolerance assessment will be conducted by the vendor if it is identified in the design requirements.

5.3.3 Test: Structural testing and jig drop tests will normally be conducted by the supplier. The functional aspects of the gear will be assessed by the airframe manufacturer, primarily in the full scale mock-up. The airframe manufacturer is responsible for the steering system functional integration since it is the combination of design efforts for two separate components, gear and control, which may be furnished by two separate suppliers. Full scale nose gear dynamic tests may be conducted on a dynamometer or test track to augment and validate the nose gear stability (shimmy) analysis math model. Functional suitability is verified by flight test.

5.4 Nose Wheel Steering System:

5.4.1 Design: The design requirements are generated by the airframe manufacturer based on the operational need for the total system. These design requirements include range, rate, shimmy damping characteristics, towing, weight, envelope and reliability and maintainability requirements.

5.4.2 Analysis: As part of the design cycle, the supplier is responsible for structural analysis of the components and fatigue assessment of the assembly. He also contributes to the airframe manufacturer's shimmy analysis of the nose landing gear assembly, but is not generally responsible for it. The hydraulic components are evaluated in the "classical" manner for leakage at adverse tolerance limits. Reliability and maintainability analyses are conducted by the supplier in accordance with the system requirements.

5.4.3 Test: Component and system tests are conducted by the supplier and/or airframe manufacturer to verify fit, function and endurance. The torque and rates are verified by the airframe manufacturer on the full scale mock-up. Free play measurements are critical for system stability. Flight tests verify operating characteristics.

5.5 Brake and Anti-Skid Control Subsystem:

5.5.1 Design: Based on airframe manufacturer requirements for response characteristics, efficiencies, etc., the suppliers compete with their own concept of system design and operation. After source selection, a major consideration is aircraft interface, brake response, aircraft stability, left to right brake cross-feed, etc. Additional system features such as built-in test, locked wheel protection, automatic braking, etc. are either solicited by the airframe manufacturer or are proposed by the supplier and accepted by the airframe manufacturer. The required system response characteristics, etc. will dictate whether or not advanced system such as digital controls are employed.

5.5.2 Analysis: Engineering analysis of anti-skid components are generally internal design tools of the supplier. The reliability and maintainability analyses are in response to system requirements of the airframe manufacturer. Adverse tolerance leakage assessment is conducted on hydraulic components. Frequently, full scale simulations are used in conjunction with production hardware for analysis of full system performance, including efficiency determination.

5.5.3 Test: Component qualification tests are conducted by the supplier and full scale simulation in conjunction with the total aircraft system are conducted either by the supplier or by the airframe manufacturer. Simulations by the supplier are limited by the data supplied by the airframe manufacturer. Dynamometer tests may be conducted, utilizing actual braking system components and hardware to a practical extent, to uncover component and system incompatibilities and determine response characteristics. Dynamometer tests should not be the sole basis for optimization of control parameters. System performance and compatibility are finally demonstrated during the flight test program.

5.6 Tires:

5.6.1 Design: Tire design effort by the supplier is aimed primarily at meeting the aircraft tire flotation requirements and specified performance spectrum on the dynamometer at a minimum weight. The design generally accounts for cut resistance, tread retention, retreadability, carcass strength, yawed roll speed effects, water spray pattern, etc.

5.6.2 Analysis: Several internal analyses are conducted by the supplier to derive the preproduction configuration.

5.6.3 Test: The supplier conducts performance and endurance tests on a dynamometer. Upon request from the airframe manufacturer, static and/or dynamic measurements of various tire characteristics are made for different system analyses. Flight testing reveals any differences in performance and wear characteristics. Retreadability is verified by a repeat of the laboratory endurance tests on tires retreaded after representative service usage.

5.7 Other Components:

Other components of the landing gear system include arresting hooks, tail bumpers, kneeling systems and crosswind control.

5.7.1 Design: Design characteristics for arresting hooks are governed by structural limitations and interface with existing or intended barrier equipment. Tail bumper design considerations are controlled by the intended use. If the unit is primarily to prevent damage during ground handling, the design characteristics are different from those required to protect the fuselage from tail strike during takeoff and/or landing. Kneeling systems and/or crosswind control design requirements are defined by the airframe manufacturer. These are usually an integral part of the aircraft system operating concept. The development cycles must reflect verification of these design conditions.

5.7.2 Analysis: Structural analysis by the airframe manufacturer and suppliers are required for components such as arresting hooks, tail bumpers, kneeling systems and crosswind controls.

5.7.3 Test: Structural tests to design, limit and/or ultimate loads and qualification tests are conducted by suppliers. Runway/aircraft interface demonstrations are conducted on mock-ups. Arresting hook performance and tail bumpers are evaluated during the flight test program.

5.8 System Operating Characteristics:

Design of landing gear components is frequently influenced by system requirements such as the following:

a. Quick turnaround capability
b. Maintenance features
c. Flotation requirements
d. Water and slush deflection requirements

5.8.1 Design: Quick turnaround capability generally impacts the brake design and results in heavier equipment. Maintenance features like gear interchangeability, etc. impacts the gear attachment and alignment. Flotation requirements have a heavy influence on tire size and spacing, gear location, and gear configuration.

5.8.2 Analysis: Flotation analysis by various approved methods provide satisfaction of the flotation requirement. The existing analysis methods provide a relative measure of actual ground operations performance but are unsuitable for realistic operational analysis.

5.8.3 Test: Turnaround capability is tested in the laboratory on a dynamometer. Maintenance features are demonstrated on a mock-up or on the actual aircraft. Ground maneuvering can be demonstrated on the aircraft but there is no assurance of correlation with flotation analysis.

6. SUBSYSTEM DEVELOPMENT:

After all component parts, and assemblies of the landing gear system are assembled into a complete and operating system, that system is expected to perform to specified requirements. This phase of development addresses these “system” requirements, and the methods of verification.

6.1 Subsystem Design:

Specific requirements for design which must be displayed by the total landing gear system include the following.

6.1.1 Documentation: Update and extension of the design, installation and integration, and component development requirements to define total subsystem requirements should be made.

6.1.2 Subsystem Schematics: Provide subsystem schematics and block diagrams to define operation of the landing gear system and its subsystems.

6.1.2.1 Hydraulic Subsystem: Update and extend block diagrams and schematics of the landing group system as initiated in part 2.

6.1.2.2 Electrical Subsystem: Update and extend block diagrams and schematics of the landing gear system as initiated in part 2.

6.2 Subsystem Analysis:

Complete subsystems involving assembly of various components, assemblies, and interfacing with other power and control systems require additional analysis.

6.2.1 Landing Gear System Stability Analysis: Specific analysis to ensure stability of the landing gear system shall be performed. Each gear installation shall be considered individually and the stability of the system as a whole should be addressed.

6.2.1.1 Nose Landing Gear Stability Analysis: Conduct an analysis of the NLG system to verify stability under the full regime of operating load, speed and time conditions, and considering input influence of major operating elements, i.e., shock strut, tires, wheels, steering/damping system and structural response of the vehicle.

6.2.1.2 Main Landing Gear Stability Analysis: Conduct an analysis of the MLG system to verify stability under the full regime of operating load, speed, and time conditions, and considering inputs of major operating elements, i.e., shock strut, tires, wheels, brakes/anti-skid system and structural response of the vehicle.

6.2.2 Hazard Analysis: Conduct an analysis of the system to identify and define any hazards in operation or maintenance of the system. Results will point out need for proper precautions for personnel or in some cases might dictate redesign or modification of the system.

6.2.3 Failure Modes and Effects Analysis: Conduct an analysis to determine the modes of failure of all elements of the system, and the effects on the system operation and the aircraft when the failure occurs. Results of this analysis may in some cases dictate redesign or modification of the system.

6.2.4 Environmental Analysis: Conduct analysis to verify satisfactory operation/performance of the system at all required extremes of environmental conditions, i.e., high/low temperature, altitude/ pressure, sand, dust, ice, sunshine, rain, humidity, acceleration, vibration, shock, etc.

6.2.5 “In-Flight Wheel Braking”: Conduct an analysis to verify satisfactory operation and strength capabilities when brakes are applied in flight immediately after lift-off either automatically or pilot applied.

6.2.6 Dynamic Analysis: Conduct adequate dynamic analysis of the system to verify operation and strength capabilities to withstand dynamic conditions which result. Some specific areas for consideration are retraction/extension system, up stops, down stops, and other mechanisms which are subject to dynamic operating conditions.

6.2.7 Reliability: Conduct analysis to verify that the system meets the requirements and criteria for reliability of operation.

6.2.8 Maintainability: Conduct analysis to verify that the system meets the requirements and criteria for ease of maintenance.

6.2.9 Flotation Analysis: Conduct analysis to verify system meets required criteria.

6.3 Subsystem Tests:

Conduct tests on the landing gear system to assure that design performance requirements are fulfilled.