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(R) Landing Gear System Development Plan

RATIONALE

This SAE Aerospace Recommended Practice is intended to provide an airframe manufacturer or landing gear system supplier guidance for planning a landing gear system development program. This revision is to introduce updates to the original release of 1985.

TABLE OF CONTENTS

INTRODUCTION

The development of a landing gear system for a modern high performance air vehicle is an engineering, manufacturing and program management process which covers many years 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. A good documented development plan will 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.

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.

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

Subsystem Development

On Air Vehicle

Post Delivery

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

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) is intended to document the process of landing gear system development. This document includes landing gear system development plans for commercial, military, fixed wing and rotary wing air vehicles.

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 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AIR5451 A Guide to Landing Gear System Integration

ARP4754 Guidelines for Development of Civil Aircraft and Systems

2.1.2 U.S. Government Publications

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: (215) 697-6396, http://quicksearch.dla.mil/.

JSSG 2006 DOD Joint Service Specification Guide – Aircraft Structures

2.1.3 ANSI Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ANSI B46.1

2.1.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAR's Part 23, 25, 27 and 29

2.1.5 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS-23, 25, 27 and 29

2.1.6 Other Publications

Aircraft Landing Gear Design - Principles and Practices, by Norman S. Currey

Landing Gear Design, by H. G. Conway

Airplane Design Part IV Layout Design of Landing Gear and Systems, by Dr. Jan Roskam

3. PRELIMINARY DESIGN DEVELOPMENT

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

3.1 Design

3.1.1 Documentation

In all stages of design, it is of paramount importance to establish the design requirements and objectives for the system and to document them. Requirements are non-negotiable while objectives are negotiable. This may be done in the form of a "System Definition Manual," "Basic Data Manual," or any similar form. This documentation should be updated as the system design progresses. Initially, requirements only will be shown. In addition to all regulatory requirements the airframe manufacturer's specific requirements need to be added as well. Prior to completion of the PDR, the means by which each requirement will be verified, should be identified. The design should be reviewed at the PDR and shown to meet all of the requirements and the verification method agreed upon.

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 the number of wheels and their spacing to meet flotation requirements for the initial configuration and all reasonable growth configurations of the airplane family. This does not mean that the initial configuration must have this many wheels but there should be a plan for growth. Careful consideration should also be given to tip-back angle, turnover angle, center of gravity limits, ground clearance to engines and 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. Wheel, tire, brake sizing should be considered for all reasonable growth configurations of the airplane family as well.

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

The number of tires/wheels, their spacing and sizing 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 shock strut piston, cylinder, trunnion, braces, supporting structure, spun and grown tires 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 the down and locked position to the 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 Studies

The preliminary design phase is the proper time for determination of basic design concepts. This requires trade studies in many cases which should include life cycle costs. Some examples of such studies might include:

a. Configuration trade

b. Brake material - steel, carbon, beryllium, etc.

c. Landing gear materials - aluminum, steel, titanium, composite, etc.

d. Auxiliary braking methods, i.e., drag chutes, arresting hook, etc.

e. Need for tail bumpers, and other auxiliary installations or devices

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 or Firm Configuration

At the end of the preliminary design phase, a basic configuration is determined and frozen. The centerline diagram of the landing gear structure is released as well as schematics of the landing gear systems architecture. This provides a baseline from which to draw up specifications and initiate design drawings/analysis of the components and installations for the landing gear and all of its systems. Adequate layout work and analyses should have been completed at this point to assure that there will be no further changes to this baseline configuration which could have a costly cascading effect.

3.2 Analysis

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

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 Steering Power Requirements

Conduct a preliminary analysis to determine power requirement for the nose wheel steering unit or main wheel steering unit, based on the geometric configuration of the A/C, the projected weight, and the desired levels of steering performance (steering angle, rate, kinematics, etc.).

3.2.6 Retract/Extend Power Requirements

Conduct a preliminary analysis to define landing gear retract/extend placard speeds to define power requirements which meet retract/extend times at placard speed.

3.2.7 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 Test

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 physical models may be utilized. 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 DEVELOPMENT

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

Major considerations for design in this phase include, but are not limited to, 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 Studies

Continue to perform trade studies to support the system integration with the aircraft and all other systems. However, studies should be limited to ideas or concepts that will yield significant improvements in performance, weight, or cost reduction as changes during this phase could present significant impacts to aircraft development schedules.

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 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 AFGS-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.

4.1.5 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 AFGS-87139 for clearances.)

4.1.6 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.

4.1.7 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.

4.1.8 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).

4.1.9 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: Provide a design layout type drawing of the arresting hook installation (as applicable) based on loads, energy dissipation capacity and dynamic analyses of the arresting gear.

e. Mooring arrangement – provide layout type drawing depicting tie down arrangement of aircraft considering most adverse placement of the aircraft in relation to arrangement of deck tie down provisions.

4.1.10 Other Auxiliary Installations

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

a. Wing tip gear installation

b. Jacking, mooring, towing, equipment installation

c. Door system installation

d. Anti-skid system

e. Indication system

f. tire de-spin devices

4.1.11 Hydraulic System Installation

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

4.1.11.1 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.

4.1.12 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.

4.1.12.1 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.

4.1.13 Wheel/Tire Failure Threat Envelope

Develop wheel/tire failure threat envelopes early according to the latest regulations. These should be available for all equipment installation reviews.

4.1.14 Lubrication Provisions

Provide design layout type drawings depicting the location and type of lubrication provisions on the landing gear that will be used for periodic lubrication of the equipment

4.1.15 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.

4.1.16 Preparation and Release of Production Drawings

Provide all engineering drawings and technical data necessary for fabrication of the landing gear system detail parts, assemblies, components, and installations.

4.1.16.1 Detail Drawings

A detail drawing provides information required for the manufacture of a single part. This type of drawing 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.

4.1.16.2 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.

4.1.16.3 Assembly Drawings

An assembly drawing is classified as one which provides information required for the manufacture of a part or component which consists of two or more detail parts.

4.1.16.4 Installation Drawings

Installation drawings provide the information necessary for installing detail parts 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.

4.1.17 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.

4.1.17.1 Component and/or Subsystem Specifications

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 Models or Drawings,” or “envelope” models or 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.

4.1.17.2 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

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

Tests conducted to support the “installation and integration” phase of design are an extension of those performed 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, landing gear integrator and component supplier.

5.1 Main Landing Gear

5.1.1 Design

The design definition of the main gear is usually a combined effort between the airframe manufacturer, the landing gear integrator, and the component supplier. Preliminary sizing is conducted by the airframe manufacturer to locate and produce an allowable design envelope and is provided to the landing gear integrator and/or component supplier in computer based solid models from Computer Aided Engineering (CAE) software packages. The airframe manufacturer establishes the design specifications including centerline drawings and loads for the landing gear assemblies. Based on conceptual proposals, etc., the integrator usually decides on the internal shock strut details, final materials and coating selection, etc., subject to airframe manufacturer approval. The mechanisms are sometimes designed and built by the airframe manufacturer, but the current trend is to outsource everything.

5.1.2 Analysis

Complete stress and fatigue analyses are completed for each component using CAE. Damage tolerances assessment is sometimes 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, gear walk, bogie pitch, etc., is conducted on the assembly. These dynamic analyses are completed by the airframe manufacturer, integrator or component supplier. Environmental analysis usually is limited to an analytical assessment. Photoelastic stress methods are less frequently used to identify stress concentrations and to refine the final designs than CAE software packages. Long lead items such as forgings are coordinated early with the airframe manufacturer or integrator.

5.1.3 Test

The primary verification tests for the main gear are structural and performance in nature. Fatigue tests are conducted to verify safety within the design envelope. Static tests may be conducted as well. These tests are most frequently conducted by the component supplier, but they can be included in the tests conducted by the airframe 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 and metering characteristics are within the design load limit (Ref AS 6053). 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 aircraft. Flight tests verify interchangeability and installation characteristics as well as energy absorption and performance.

5.1.4 Additional Requirements for Aircraft Carrier Based Aircraft

The whole aircraft may be drop tested in lieu of a jig drop test. However, Jig drops are normally performed to verify energy absorption and metering characteristics are within the design load limit. 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 airframe manufacturer typically completes sizing, layouts and envelope documentation for the wheel and brake equipment, including the nose and main wheel. These are finalized after preparation of CAE generated interface control drawings, design/performance specifications and related documentation of all design/performance requirements. The component supplier designs the main wheel/brake and nose wheel proposal 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 or integrator.

5.2.2 Analysis

The key analyses of the wheel and brake are the thermal, energy performance and structural analyses conducted by the component supplier to meet all design and performance requirements of the airframe manufacturer. Usually, this is subject to customer or regulatory agency approval. Loads analyses and environmental analyses are used to finalize design requirements. Reliability, maintainability, stress and interface analyses are conducted by the component 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 component supplier in the form of static tests (limit and ultimate) 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 component supplier to verify design performance in energy absorption, durability, torque characteristics, environmental compatibility, interface compatibility, thermal performance (fuse release in braked wheels), operating characteristics and anti-skid brake control systems compatibility. Special tests of various special features or characteristics may be dictated by the airframe manufacturer's design/performance specification. Minimum levels of performance are established for safety of flight demonstration for all airworthiness flight testing to begin. 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, towing (conventional and towbarless), aircraft carrier use, 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 standard ground support equipment such that the nose landing gear cannot be operated outside its design limits. Based on conceptual proposals, etc., the integrator usually decides on the internal shock strut details, final materials and coating selection, etc., subject to airframe manufacturer approval. The mechanisms are sometimes designed and built by the airframe manufacturer, but the current trend is to outsource everything.

5.3.2 Analysis

As with the main gear, the component supplier shall conduct stress and fatigue analyses. Preliminary stress and fatigue analyses are completed for each component using CAE. Damage tolerance assessment is sometimes 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 is conducted on the assembly. This dynamic analysis is completed cooperatively. The airframe manufacturer, integrator and component supplier will conduct measurements of deflection and spring rates, which will be major contributions for the shimmy analysis. Environmental analysis usually is limited to an analytical assessment. Photoelastic stress methods are less frequently used to identify stress concentrations and to refine the final designs than CAE software packages. Long lead items such as forgings are coordinated early with the airframe manufacturer or integrator.

5.3.3 Test

The primary verification tests for the nose gear are structural and performance in nature. Fatigue tests are conducted to verify safety within the design envelope. Static tests may be conducted as well. These tests are most frequently conducted by the component supplier, but they can be included in the tests conducted by the airframe 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 and metering characteristics are within the design load limit (Ref AS 6053). 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 aircraft. Flight tests verify interchangeability and installation characteristics as well as energy absorption and performance. The airframe manufacturer or integrator is responsible for the steering system functional integration since it is the combination of design efforts for two separate components, gear and control, which is usually furnished by two separate component 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 CAE 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 (refer to ARP1595).

5.4.2 Analysis

As part of the design cycle, the component supplier is responsible for structural analysis of the components and fatigue assessment of the assembly. The component supplier also contributes to the airframe manufacturer's or integrator's CAE 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 component supplier and/or airframe manufacturer to verify fit, function and endurance. The torque and rates are verified by the airframe manufacturer or integrator 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 or integrator requirements for response characteristics, efficiencies, etc., the component 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 integrator or are proposed by the component supplier and accepted by the airframe manufacturer or integrator. 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 component supplier. The reliability and maintainability analyses are in response to system requirements of the airframe manufacturer or integrator. Adverse tolerance leakage assessment is conducted on hydraulic components. Frequently, full scale simulations (hardware-in-the-loop) are used in conjunction with production hardware for analysis of full system performance, landing gear stability, and efficiency determination.

5.5.3 Test

Component qualification tests are conducted by the component supplier and full scale simulation in conjunction with the total aircraft system are conducted either by the component supplier or by the airframe manufacturer or integrator. Simulations by the supplier are limited by the data supplied by the airframe manufacturer or integrator. 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 but this is not usually necessary. 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 tire 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 wear performance, 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 tire supplier conducts performance and endurance tests on a dynamometer using a steel wheel design for ease of test. 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 Gear Retraction/Extension System

5.7.1 Design

The design requirements are generated by the airframe manufacturer based on the operational need for the total landing gear retraction/extension system. These design requirements include extension type (free fall versus powered), retraction braking, retraction rate, uplocks and downlocks, weight, envelope and reliability and maintainability requirements.

5.7.2 Analysis

As part of the design cycle, the component supplier is responsible for structural analysis of the components and fatigue assessment of the assembly. The component supplier also contributes to the airframe manufacturer's or integrator's CAE retraction/extension analysis of the 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 component supplier in accordance with the system requirements.

5.7.3 Test

Component and system tests are conducted by the airframe manufacturer or integrator to verify fit, function and endurance. The retraction/extension rates are verified by the airframe manufacturer or integrator on the full-scale mock-up. Flight tests verify operating characteristics.

5.8 Other Components

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

5.8.1 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 or integrator. These are usually an integral part of the aircraft system operating concept. The development cycles must reflect verification of these design conditions.

5.8.2 Analysis

Structural analysis by the airframe manufacturer or integrator and component suppliers are required for items such as arresting hooks, tail bumpers, kneeling systems and crosswind controls.

5.8.3 Test

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

5.9 System Operating Characteristics

Design of landing gear components is frequently influenced by system performance requirements for quick turnarounds, reliability and maintainability and flotation.

5.9.1 Design

Quick turnaround capability generally impacts the wheel, brake and tire design and results in heavier equipment. Maintenance and reliability features like gear interchangeability, un-handed shock struts and brakes, etc. impacts the gear design, attachment, alignment and cost. Flotation requirements have a heavy influence on gear configuration, tire spacing and tire size.

5.9.2 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.

5.9.3 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 Design

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

6.1.1 Documentation

Update 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 drawings/schematics and block diagrams to define operation of the landing gear system and its subsystems.

6.1.2.1 Hydraulic Subsystem

Update block diagrams and drawings/schematics of the landing group system as initiated in the preliminary design.

6.1.2.2 Electrical Subsystem

Update block diagrams and drawings/schematics of the landing gear system as initiated in the preliminary design.

6.2 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 CAE 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 a CAE 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 both new and worn, i.e., shock strut, tires, wheels, steering/damping system and structural response of the air 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 both new and worn, i.e., shock strut, tires, wheels, brakes/anti-skid system and structural response of the air 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.