AN INTEGRATED MODULAR TEST RIG FOR LANDING GEAR FATIGUE AND STRENGTH TESTING

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Abstract

This paper describes the design and implementation of a modular test rig for full-scale fatigue and strength testing of aircraft landing gears. The test rig is designed to reduce set-up lead time and rig procurement costs through the use of standardised components. The key components consist of a T-slot machine bed for the mounting of all rig components, a set of universal simulated wheel assemblies for transferring ground loads to the landing gear axles, and modular reaction frames for the mounting of loading actuators. In addition, instrumentation, wiring, and hydraulics have been standardised on the rig and throughout the test lab to reduce the total cost of procurement and allow rapid set-up and part interchange.

Specific components of the rig design are discussed, including the design of the reaction frames. The modular frames form an integral portion of the rig design. They are designed to react loads from horizontally mounted actuators which are attached to linear bearings to permit the loading actuators to be automatically maintained level as the test article deflects. This automatic levelling system also permits the test controller to change the landing gear shock strut stroke without interrupting the progress of the fatigue test. The frames are also used to distribute hydraulic fluid and electrical connections to the loading actuator and the levelling actuator, thus reducing the amount of cables and hoses exposed on the test rig.

Figure 1: Integrated Modular Test Rig

1 Introduction

Aircraft landing gears are designed and manufactured to suit a particular aircraft geometry. Every aircraft carries an undercarriage designed to meet the specific requirements of that aircraft and its operational needs.

As part of the aircraft certification process, each landing gear requires testing to demonstrate adequate structural strength and fatigue life [1,2,3]. Development testing such as stiffness and strain surveys are performed to assist the development of stress analysis models. Certification and development tests are conducted using the same test rig and test article configuration. These strength and fatigue tests are performed using hydraulic actuators controlled by a load control system in a dedicated reaction frame.

Although each landing gear is specific to an aircraft, landing gear styles may be reduced to three fundamental geometries: cantilever, trailing link, and bogie. Each undercarriage type shares some similarities – all connect to an airframe, contain some sort of shock absorber, and carry a wheel or more mounted on one or more axles.

The variation in landing gear geometries can make the creation of test rigs for each gear a daunting and expensive task. However, the similarities inherent in the landing gear concept allow for a standard rig to be produced that can test each type of landing gear with common parts and reconfigurable, modular equipment.

2 Cost Savings

2.1 Cost Reduction Initiative

The concept of developing an integrated modular test rig (Figure 1) was driven by the initiative to reduce the overall cost of performing landing gear structural testing. Three primary methods were identified: reduce the time required to design and manufacture test rigs, reduce the time required to set-up a test, and reduce the amount of time required to run the test. Other costs that were highlighted for reduction were costs associated with planned and unplanned maintenance of the rig.

Reduction in the running time of the test could be achieved by optimising the parameters of the load control system and by optimisation of the rig's structural and hydraulic arrangement. Optimisation of the structure and hydraulics was a prime consideration in the design of the standard rig. Fine tuning of the load control system and optimisation of the load profile were already established procedures in the test lab, and it was felt that there was little to be gained in this area while there were large opportunities for improvements in the other areas.

2.2 Rig Cost Reduction

Traditionally, rigs in the test lab were custom designed to perform testing on one landing gear. Where possible, rigs from previous tests were adapted for new test programs. There was no effort made to standardise items used on the rigs. The introduction of the standard rig concept acknowledged that a slightly larger initial investment would reap rewards in the future by significantly reducing the cost of future tests.

For instance, the standard rig discussed in this paper cost only 33% more than a recently procured custom rig. The cost of doing a second test using this rig is estimated at only one third the cost of a custom rig - less if actuators and load cells could be reused. Thus, the initial extra expense of the standard rig is justified with only two tests.

2.3 Set-up Time Reduction

The amount of time required to initially configure the standard rig is reduced through the use of modular components. Rather than provide one large superstructure, the rig is composed of a machine bed plate to which identical, modular reaction frame components are affixed.

The modular frames contain electrical wiring and hydraulic plumbing to facilitate interconnection to loading actuators and load cells. Standard electrical and hydraulic connectors allow quick and dependable connections. The modular structure of the frames and the machine bed attachment allow a test to be rapidly reconfigured. This feature permits significantly reduced test set-up time.

3 Rig Design Features

3.1 Machine Bed Baseplate

A T slot machine bed baseplate was installed in the test lab floor. The T slots (Figure 2) provide a convenient method to attach reaction structure to the plate. The machine bed is anchored to a floating concrete slab through levelling anchor bolts. The baseplate measures 8 m x 6.5 m. This size allows for two or three tests to be conducted on the one area.

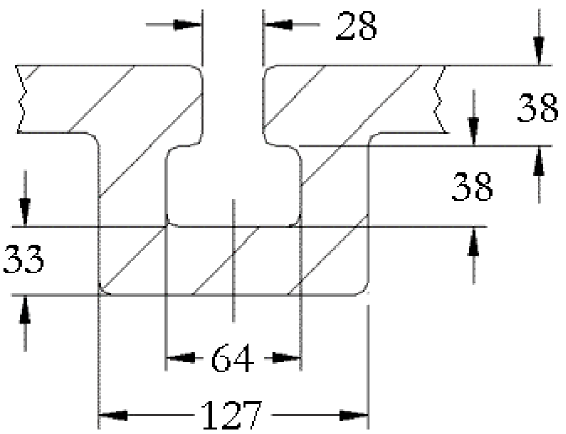

Figure 2: T slot arrangement

Connection of the other rig components to the baseplate is provided through custom T nuts, grade L9 bolts, and clamp bars. Each bolted connection to the baseplate has a maximum design load of 90 kN.

3.2 Trunnion Mounting Bracket

The only portion of the rig that is truly landing gear specific is the trunnion mounting bracket (Figure 3). This bracket simulates the aircraft attachment points and anchors the trunnion of the landing gear and any braces to the baseplate. The bracket is designed to be nearly rigid; aircraft stiffness is not modelled. The one piece bracket is a cost-effective structure that can serve reliably through the required three to five fatigue lifetimes. Trunnion mounting brackets incorporate aircraft bearings or bushings at the landing gear interface.

Additional benefits are reaped in the lab whereby the trunnion mounting plate design for a specific landing gear can be used on several different types of tests. Due to test schedules, three (or possibly four) trunnion plates are procured – drop, endurance, strength, and fatigue testing can all use the same trunnion bracket design.

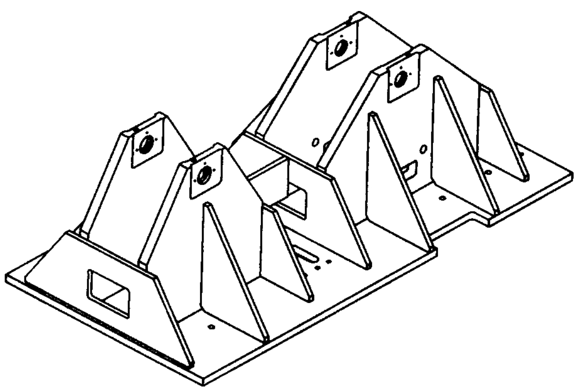

Figure 3: Trunnion mounting bracket

3.3 Reaction Frames

The modular rig requires that landing gears be mounted in the rig in an inverted position. The inverted position also facilitates installation of the test article into the rig. Inversion of the test article allows the vertical load components to be applied by reacting against the baseplate rather than requiring substantial additional structure to be mounted on the top of the rig. Other loads (side and drag loads) must be applied to the axles parallel to the baseplate.

To react these loads, universal modular frames (Figure 4) are used. On the current test, pictured in Figure 1, eight frames are used to react side and drag loads. Each frame provides an internal distribution of hydraulic fluid and electrical connections. Both hydraulic and electrical connectors conform to the test lab standards to allow the use of standard cabling and hydraulic hosing.

The frames are a welded assembly of structural steel. Mounted to each frame is a linear bearing to allow the loading actuator to be positioned in the vertical dimension. An additional hydraulic actuator is provided to allow positioning of the loading actuator for set-up purposes and to maintain the loading actuator horizontal during the test.

The top of each frame is fashioned into a flange with a bolt pattern to facilitate the attachment of stiffening beams. The stiffening beams tie the modular frames together to allow higher horizontal forces to be reacted than that permitted for a single frame. The stiffening beams also provide a convenient location for the attachment of hoisting apparatus and loading actuator counter weighting mechanisms.

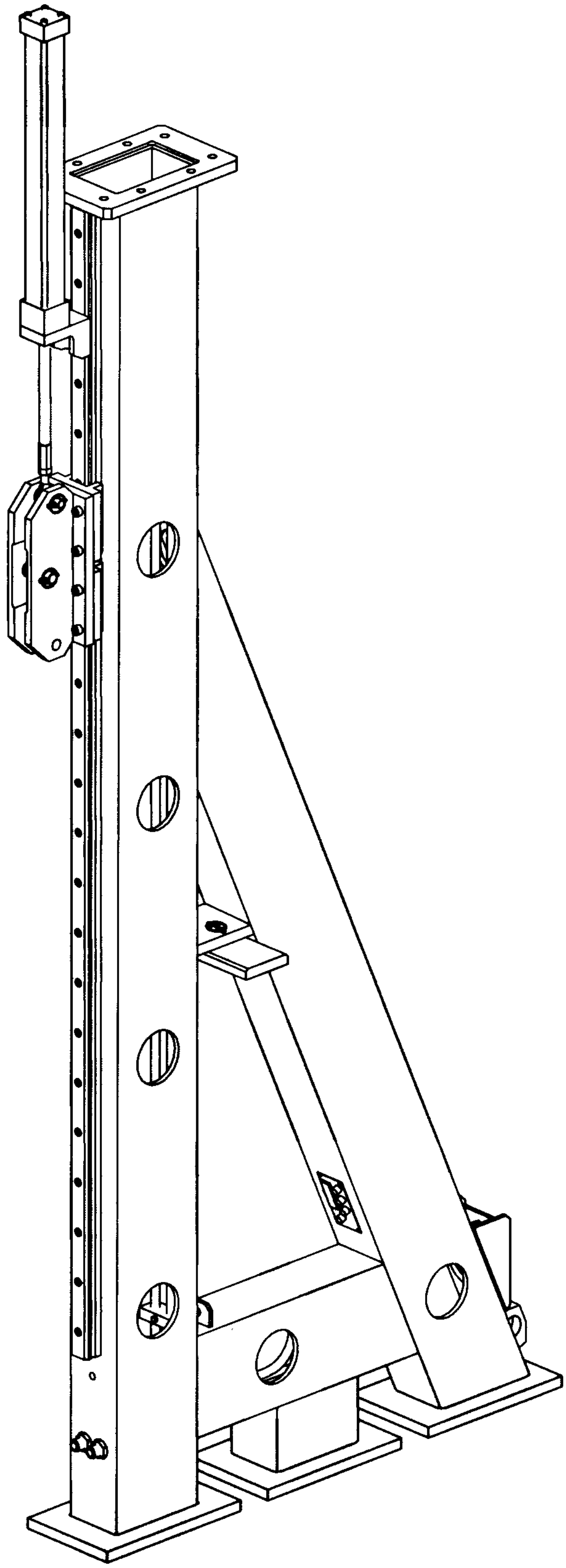

Figure 4: Modular Reaction Frame

3.4 Actuator Levelling Control

The inclusion of active actuator levelling serves three purposes. For set-up, a pendant hand control may be connected to the levelling controller to allow manual positioning of the loading actuator. When the pendant is disconnected, the levelling actuator will actively maintain the loading actuator in a level position. This is used to keep the loading force vector parallel to the baseplate when the test article deflects, thus reducing errors in force application. Level control also permits the shock strut position to be changed during a test at the direction of the test controller. When the shock strut is hydraulically actuated, the loading actuators will be maintained in their proper position. This feature eliminates the need for manual repositioning of the loading actuators when a load case change is required.

Each positioning actuator has a manifold mounted solenoid selector valve. Flow through the valve to the cylinder is metered using a hydraulic throttle and check sandwich module. This allows the speed of the unequal area actuators to be maintained equal in both directions.

The selector valves use direct current coils for actuation. On top of the valve, mounted to the coil connection, is an independent levelling controller. The levelling controller takes direct current power input (routed through the reaction frames) and uses this to control the levelling valve.

A micro-machined accelerometer is used as a tilt sensor to measure the angle of the loading actuator to the horizontal. A microcontroller within the levelling controller then commands the levelling valve in the appropriate direction to maintain the loading actuator in the horizontal position.

3.5 Simulated Wheel Assembly

A costly and complicated assembly used for landing gear fatigue and strength testing is the simulated wheel, which provides a mechanism to transfer loads to the landing gear axle. At a minimum, vertical load, side load, and drag loads are applied. Depending upon the test requirements, the drag and side loads may need to be applied at varied positions - often at the axle or rolling radius of the tire. In some instances, differential side loading must be applied to simulate torsion loading of the gear.

There are two obvious criteria that dictate the design of the simulated wheels: applied force magnitude and axle size. To design a truly universal simulated wheel would be impractical. A simulated wheel sized for the largest forces would simply be too large and heavy for smaller landing gear. A set of universal wheels sharing similar designs would be a more reasonable approach.

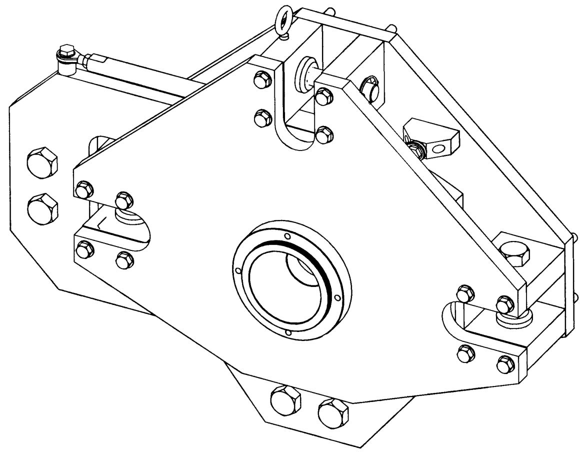

Figure 5: Universal Simulated Wheel

A simulated wheel for the moderate force category was developed for the standard test rig (Figure 5). The simulated wheel allows for loading actuator attachment for all common load points. The attachment points are adjustable for different rolling radii.

The problem of varying axle diameters was approached by adopting a ‘bearing can’ that is mounted into the simulated wheel. This can is designed specifically for a certain landing gear. The can carries internally bushings of the appropriate size to mate with the landing gear axle. The exterior of the can is always identical, which permits rapid installation into the simulated wheel assembly.

3.6 Loading actuator

The loading actuators (Figure 6) used on the modular rig are provided as an integrated solution by the actuator vendor. Each integrates a servo valve on the actuator through an integral manifold. Hydraulic quick disconnects are furnished to allow rapid connection to the servo valve. The mechanical attachment points on the actuator are tailored to mate precisely with the load cell and the levelling fixture. Considerable cost and time savings were realised by using the cylinder manufacturer to provide a fully integrated and tested solution for the rig.

Figure 6: Loading Actuator

3.7 Hydraulic Protection Module

A standard item in the test facility is an internally developed hydraulic protection module. The module is designed as a sandwich module, to fit between a servo valve and the servo valve manifold. In this way it can be applied or retrofitted to any existing test as well as new loading actuators. A schematic diagram of this module is shown in figure 7.

The entirely passive module provides adjustable relief valves to limit the maximum load that the actuator is capable of providing. In addition, it provides an actuator dump capability when pump pressure is lost. This feature was integrated due to the large amount of cyclic endurance testing performed in the lab where it is possible for one mechanism to drive against a stationary loading actuator. To avoid the possibility of damage when the dump valve actuates on a strength or fatigue test, a needle valve is provided to allow a variable restriction. In this way, should pump pressure fail during a test, the test article stiffness will force the loading actuators to zero in a relatively slow period of time.

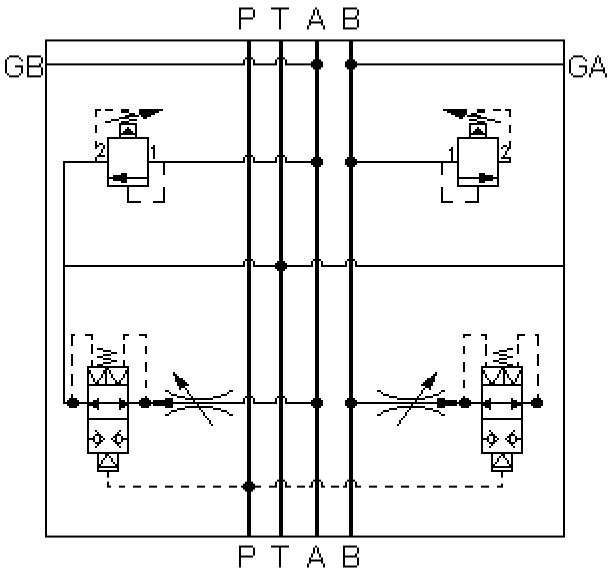

Figure 7: Protection Manifold Schematic

The safety features of the module are adjustable for both ports of the loading actuator to allow the use of unequal area cylinders and asymmetric tension and compression loads.

4 Conclusions

The decision to invest in a standardised rig has many benefits. The initial higher cost (33% in this instance) is more than made up for in secondary testing, where the cost of doing a second test is only one third of a traditional test investment. Additional benefits are reaped through the reduction in inventory required to maintain the test rig. The use of modular equipment means that initial purchase prices can be lower as component manufactures may take advantage of economies of scale. The inclusion of levelling actuators and controllers allows for a more precise test, while providing benefits in terms of reduced test run times.

5 References

[1] Federal Aviation Authority. Federal aviation regulations, part 25.

[2] Transport Canada. Airworthiness manual, chapter 525.

[3] Joint Aviation Authority. Joint aviation requirements, part 25.