Chapter 1 Introduction

1.1. Introduction

The design of the landing gear, which is considered "the essential intermediary between the aeroplane and catastrophe" [1], is one of the more fundamental aspects of aircraft design. The design and integration process encompasses numerous engineering disciplines, *e.g.*, structures, weights, runway design, and economics, and has become sophisticated in the last few decades.

The landing gear design process is well-documented by Conway [1] and more recently by Currey [2] and is experience-based and graphically-oriented in nature. As such, it is a key responsibility of the configuration designer during initial concept studies. However, as industry and government try to incorporate multidisciplinary design optimization (MDO) methods in the conceptual design phase, the need for a more systematic procedure has become apparent. Accordingly, NASA Ames provided Virginia Tech with a two-year research grant to develop a landing gear design methodology that can be implemented within an MDO environment, with a special emphasis on design considerations for advanced large subsonic transports. The result of this research project, known as *Landing Gear Integration in Aircraft Conceptual Design*, is the topic of this report.

1.2. Overview

Several design considerations that must be addressed are briefly discussed to illustrate the complexity involved in the development of such a methodology. The list is made up of an ever-increasing, and sometimes conflicting, number of requirements, *e.g.*, component maximum strength, minimum weight, high reliability, low cost, overall aircraft integration, airfield compatibility, *etc.*, and truly reflect the multidisciplinary nature of the task.

The weight of the landing gear, which typically ranges from three to six percent of the maximum aircraft takeoff weight, is also a design consideration. With advances in flight science technologies, which result in reduced structural and mission fuel weights, the landing gear may become an increasingly large weight fraction in future large aircraft. Figure 1.1 illustrates the issue. Several typical weight estimating equations are compared with data tabulated by Roskam[3]. The figure also contains recent estimates from Boeing and Airbus for their proposed new large aircraft designs. In particular, note the difference in trends between the ACSYNT and Douglas and Torenbeek equations for weights above a million pounds. It is particularly interesting to note that the Airbus estimate agrees with both the ACSYNT and Douglas equations. However, which trend is correct? Because the curves cross at this point, it is impossible to tell which estimate is appropriate. Thus, one design objective of the study is to be able to estimate the weight of the landing gear early in the design phase using a first principals analysis. A major reduction in the landing gear weight may be hard to realize because landing gears are one of the few non-redundant load-paths in an aircraft, and any reduction in reliability from current fail-safe standard is not acceptable [4].

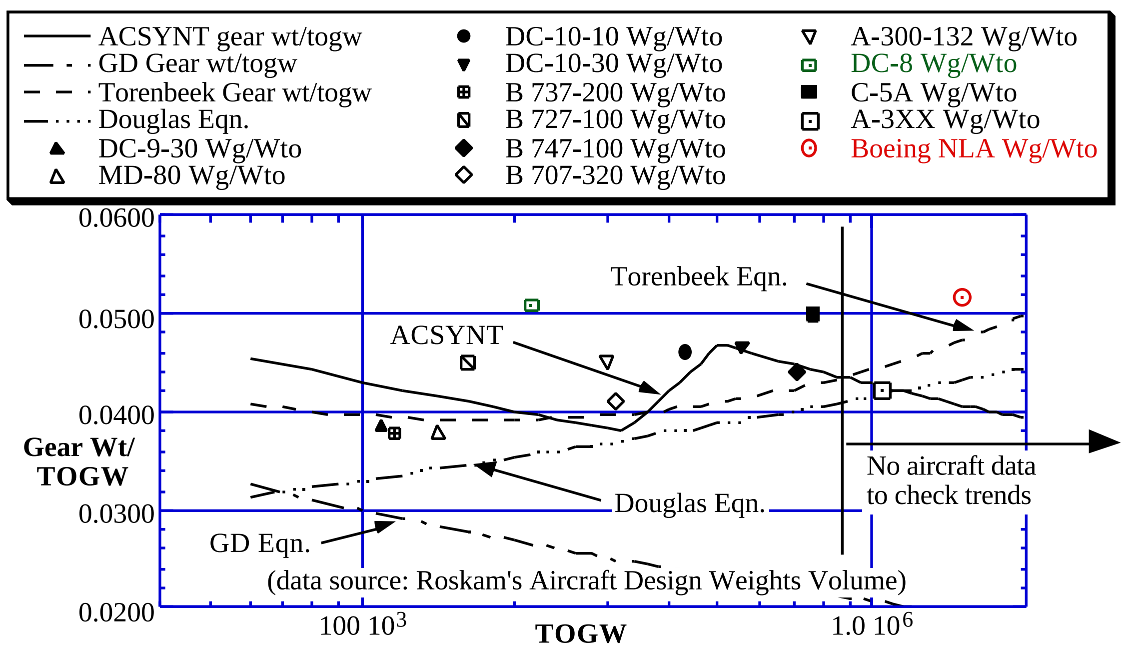

Figure 1-1. Initial comparison of weight equations with aircraft weights data.

The location of the aircraft center of gravity (*cg*) is critical in the design and location of the landing gear. The nose and main assemblies must be located within specific distances from the aircraft *cg*, in both the longitudinal and lateral directions, such that the aircraft is in no danger of tipping back[1] or turning over on its side over the full range of *cg* locations under static or dynamic conditions. Another issue to be considered is the distribution of the aircraft weight, which is dependent on the distances between the aircraft *cg* and the nose and main assembly. Between 85 and 92 percent of the MTOW must be maintained on the main assemblies such that the brakes can provide sufficient energy to slow down the aircraft within a given runway length [5].

Airfield compatibility has become one of the primary considerations in the design of landing gears due to the high cost associated with infrastructure modification, *e.g.*, pavement reinforcement and runway and taxiway expansion[6].[2] Pavement bearing strength, which varies from one airport to another due to variations in subgrade materials, dictates the number and arrangement of tires needed to produce the required flotation characteristics. Flotation is defined as the capability of the runway pavement and other surfaces, *e.g.*, taxiway and apron, to support the aircraft. In addition, the disposition of the landing gear is constrained by the runway and taxiway geometry as found at the airports to be served. Since the ground track is dependent on the dimensions of the wheelbase and track, an increase in these dimensions could bring the aircraft over the edge of the pavement during certain maneuvers, *e.g.*, a 180-degree turn and centerline-tracing taxiing, and cause the aircraft to bog down in soft soil [7].

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[1] Some aircraft have tail props to ensure that the aircraft does not tip back while parked at the gate. From the AIAA case study series on the 727: "When the first National Airlines 727-200 rolled to a stop as it was delivered in Miami, the pilot touched the brakes, the airplane nose went down and then recoiled up, lifting the nose gear off the concrete about 6 to 8 inches. The gasp in the crowd were heard 3,000 miles away in Seattle. ... As far as we know, no 727-200 has ever sat on its tail and maybe we overreacted to the National incident, but that's why you will nearly always see a 727 with its rear airstairs down when parked. There are some rare cases where we attach lead to the radome bulkhead for extreme loading conditions." Note that the *cg* range of the 727-200 ranges from 8 to 42% of the mac.

[2]The prototype B-36 had single large main wheels, 110 inches in diameter. They were the largest aircraft wheels ever made. They required a 22 1/2 inch thick runway, thus limiting the prototype to three specially strengthened runways, those at Fort Worth, Eglin AFB and Fairfield-Suisan AFB (later Travis AFB also). A multi-wheel gear could not be obtained until adequate brakes could be designed. Finally, a four-wheel gear using 56 inch diameter tires was perfected for the B-36A. A 13 1/2 inch thick runway was needed, and 22 primary and a further 22 alternate air fields could handle the production bombers. (source: Meyers K. Jacobson and Ray Wagner, *B-36 in action*, squadron/signal publications Aircraft No. 42, 1980, the initial TOGW of the B-36 was 265,000 lbs, and grew to 360,000 lbs.).

The soundness of a landing gear concept depends on the efficacy of overall system integration. Ground clearance, particularly between the engine nacelle and the static groundline, plays a key role in determining the length of the landing gear and the permissible takeoff rotation angle. Insufficient allowance can result in costly modifications, *e.g.*, lengthening of the strut with concomitant stowage constraints or complicated strut shrinkage mechanisms, or repositioning of the under-wing engines, that effectively rule out future growth options.* The landing gear stowage issue must also be addressed as the number of main assembly struts increases with the increase in aircraft weight [8]. Trade-off studies concerning space availability, structural integrity, and weight penalties resulting from local structural reinforcements are needed to arrive at an optimum design.

With the financial challenges arising from the deregulation of the air-travel industry, airlines need to reduce operating costs to remain competitive. As a result, airlines are demanding that aircraft manufacturers produce new designs with high reliability and low maintenance requirements. Recent technologies, *e.g.*, carbon-carbon heat sinks, radial tires, and high-strength steel, are being introduced. In addition, simplified design and improved manufacturing techniques, *e.g.*, die-forging and three-dimensional machining [9], are being used to reduce the part-count associated with the landing gear system.

1.3. Objectives

The development of an MDO-capable design methodology is focused on providing the conceptual designer with tools to help automate the disciplinary analyses, *i.e.*, geometry, kinematics, flotation, and weight. Documented design procedures and analyses as found and referenced by Curry [2] and Torenbeek [3] were examined to determine their applicability, and to ensure compliance with current practices and regulations. Although in most cases the documented analyses were developed for a specific type of aircraft, the essential fundamentals remain unchanged for any type of aircraft. Thus, using the latest information as obtained from industry during an initial industry survey [App. A], the analyses were developed to accommodate the design criteria associated with possible advanced large subsonic transports. Algorithms were then developed based on the updated analysis procedures as a package to be incorporated into existing MDO codes.

* This was the case with the Boeing 727.