

The 747-400 Dreamlifter – Swing Tail Door Alignment and Latch Mechanism

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ABSTRACT



One essential feature of the 787 production system is the 747-400 Large Cargo Freighter (LCF), also known as the Dreamlifter,^[1] and its ability to quickly and efficiently transport large components from global manufacturing locations to the final assembly site in Everett, Washington. This unique airplane has a tail section (Swing Tail) that opens to allow cargo loading. Quickly loading and unloading cargo is largely dependent on the reliable operation of the integral swing tail door alignment and latching systems.

The swing tail door is approximately 23 feet horizontally by 29 feet vertically in size. The alignment and latching systems are required to function in a wide range of environmental conditions including temperature extremes and high winds. At the same time, these systems must ensure that flight loads are safely transmitted from the tail to the airplane fuselage without inducing undue fuselage preloads and without excessive play in the latching system. These requirements presented a developmental challenge that called for an innovative solution for adjustment of the latching and alignment mechanisms.

INTRODUCTION

The new business model for producing the new 787 airplane necessitated development of a global transportation system. Suppliers of large integrated sections of Boeing's 787 are located in Asia, Europe and North America, with final assembly performed in Everett Washington. The key question was then how to transport these components to Everett.

Based upon internal Boeing studies, the best solution for meeting the 787 global logistics plan for transportation of these large, fully assembled fuselage and wing components was determined to be by air transport^[2]. This decision led to the development of what was then known as the LCF. The next important part of the process was to then determine what aircraft the design should be based upon, as well as how to rapidly and reliably load/unload aircraft components.



Figure 1- LCF Being Loaded with Fuselage Section

747-400 DREAMLIFTER

The 747-400 passenger airplane was chosen as the basis for the LCF airplane. When specially modified for the mission, it was the closest fit for the design requirements in terms of payload/range, capability and availability. The Dreamlifter program was launched in late 2003 with type certification occurring in the spring of 2007. This aggressive schedule, along with the plan to limit the number of Dreamlifter aircraft produced, focused the design effort on reliability, performance, common pilot type rating and 787 cargo operations while preserving existing 747-400 structures and systems as much as possible. With the majority of the lower fuselage, wing and empennage structures and systems unchanged, the LCF modification is mainly comprised of the following:

- Addition of a pressure bulkhead to separate the forward pressurized fuselage section from the large unpressurized aft cargo compartment.
- Strengthening of the main deck floor structure.
- Larger diameter upper fuselage.
- Addition of the swing zone to allow cargo loading into the aft end of the fuselage through the open swing tail section.
- 120 inch aft fuselage body extension along with a 60 inch extension of the vertical stabilizer to move more of the stabilizer up and out of the airflow disturbed by the larger diameter upper fuselage.
- Removal of Winglets.

LOADING CONCEPTS CONSIDERED FOR LCF

To enable quick loading and unloading of cargo, several cargo door concepts were evaluated. Considered were clam shell doors at the forward end, a swing nose, space shuttle type cargo doors that would open the top of the fuselage, and a large traditional style side cargo door aft of the wing. Two other interesting configurations also considered were a removable tail and a vertical swingtail. After a thorough evaluation of these concepts, the lateral swing tail (see Figure 2) emerged as the best option in terms of structural capability, design effort and manufacturing technology.

SWING ZONE

The functional heart of the Dreamlifter is the swing zone, a fuselage section consisting of four frame bay sections both forward and aft of the swing tail hinge centerline. It is an all-new reinforced fuselage section designed to transmit all fuselage flight loads through 25 discrete load transfer points between the forward fuselage and the tail section of the airplane. The load transfer points consist of 21 individual latches and four hinge fittings. This configuration allows the tail section of the airplane to be rotated to the left side to accommodate loading of cargo.



Figure 2 – First Swing Tail Opening ^[3]

An early swing zone concept consisted of a vertical hinge line outside of the body with only two hinges at top and bottom. The hinges would only be used for swing operations and not transmit flight loads. In addition, 28 latches were evenly distributed around the fuselage circumference. This early concept was refined to the current configuration of a slightly canted hinge line located inboard of the fuselage frame outer chord at the intermediate hinge locations. Relocating the hinge line inside the frame results in a significant reduction of moment due to vertical load placed on the hinges – for this reason, the main upper and lower hinges do not carry vertical loads. The weight penalty would have been very large in order to safely react the moment due to vertical loads.

The upper and lower main hinges therefore only transfer horizontal flight and swing tail operation loads. The two intermediate hinges transfer all vertical hinge loads as well as the horizontal swing tail operation and flight loads. The addition of the intermediate hinges on the frames also results in the advantage of a better load distribution, which allows for the use of fewer latches. The 21 radially oriented latches carry forward/aft and shear flight loads. This intermediate hinge addition did however result in the need for articulated covers for the intermediate hinges. These intermediate hinge covers are slaved to the movement of the swing tail, and are required to quickly open in order to move out of the way during swing tail operations.

Earlier swing tail concepts also included a self contained actuation system with mechanical or hydraulic actuators to control the movement of the swing tail. This is similar to the operation of some other smaller swingtail aircraft. In the end, due to the size of the swing tail, it proved more efficient to add ground support equipment to actuate the rotation of the swing tail. This decision led to the creation of the Mobile Tail Support (MTS) vehicle (see Figure 3). The MTS is a specially modified heavy lift truck chassis, its lifting mechanism replaced with a sophisticated support mast that provides support for the swing tail and ensures its safe operation ^[5]. The MTS and LCF have mechanical and software lockouts that

prevent removal of the MTS prior to the swing tail being in a closed, latched and locked condition or opening of the swing tail prior to the MTS being attached to the swing tail and ready to operate.



Figure 3 – Mobile Tail Support

SWING TAIL LATCHING

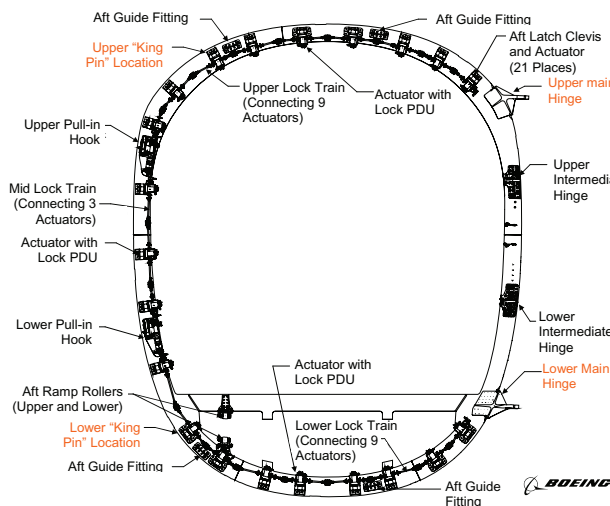


Figure 4 – Swing Zone Looking Aft

Once the decision had been made to utilize a swing tail type configuration, the next steps were to determine how to reliably latch and unlatch the swing tail from the forward fuselage in a repeatable manner. Considerations had to include the transfer of flight loads between the sections and the type of latching system to use. The chosen design had to meet all current Federal Aviation Regulations (FARs) for transport aircraft doors. Latching system concepts considered included bayonet type devices, hook type devices, shear pins parallel to fuselage skin with separate shear fittings and shear pins normal to the fuselage skin, in a radial arrangement. The merits of each were discussed and the radially oriented shear pin-type latches were eventually selected as the best choice. The latching devices chosen for the LCF application were originally developed for the 777 wing-fold mechanism. This proven latch actuator had a latch pin with the capability to take the high loads required. The integrated, yet separately powered

latching and locking features allowed the required FARs to be met. The radial latch actuator arrangement was chosen to minimize the effects of thermal variations on latching and unlatching as well as simplifying the load transfer model by transferring forward/aft and shear loads in one configuration. In order for the latch actuators to stay outside the 787 cargo envelope, they had to be placed on the swing tail side of the swing zone. This in turn required the placement of the hydraulic actuation system in the swing tail which put an additional burden on the electrical wiring system as it was routed to the aft section through an already crowded hinge line.

SWINGTAIL ALIGNMENT

In order to account for the possibility of gross misalignment between the swing tail and the forward fuselage, a ramp (Figure 6) was added which protrudes from the forward fuselage and engages the swing tail as it closes. The ramp was designed to align the swing tail with the fuselage during closing operations in all operating wind conditions by engagement of upper and lower ramp rollers mounted on the swing tail. The ramp reduces swing tail deflections and provides proper positioning for the intermediate alignment devices (Centering Guides). The length of the ramp was determined by the swing tail open angle at which the latch lug and clevis nearest to the hinge line start their engagement. A shorter ramp would risk interference issues in high wind conditions due to swing tail deflection relative to the forward fuselage.

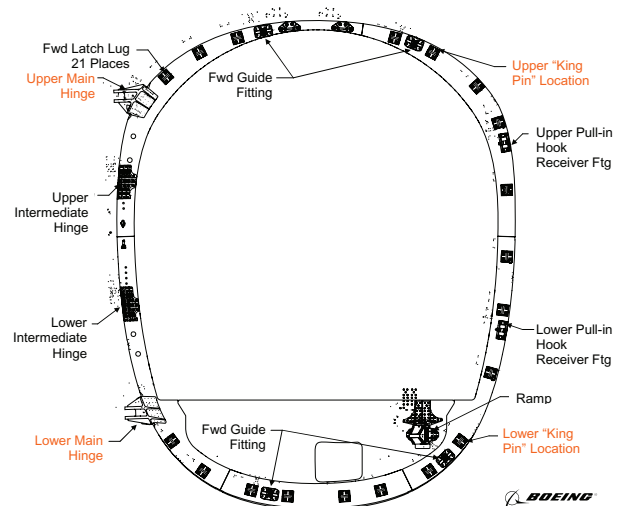


Figure 5 - Swing Zone Looking Forward

The height of the ramp was determined by Finite Element Models (FEMs) that provided guidance as to the extent of deflections for various wind conditions during closing. As the ramp protrudes aft about 4.5 feet, there was potential for accidental damage. To mitigate this risk, the ramp and its supporting structure were