The Boomerang Military Flying Straddle Carrier

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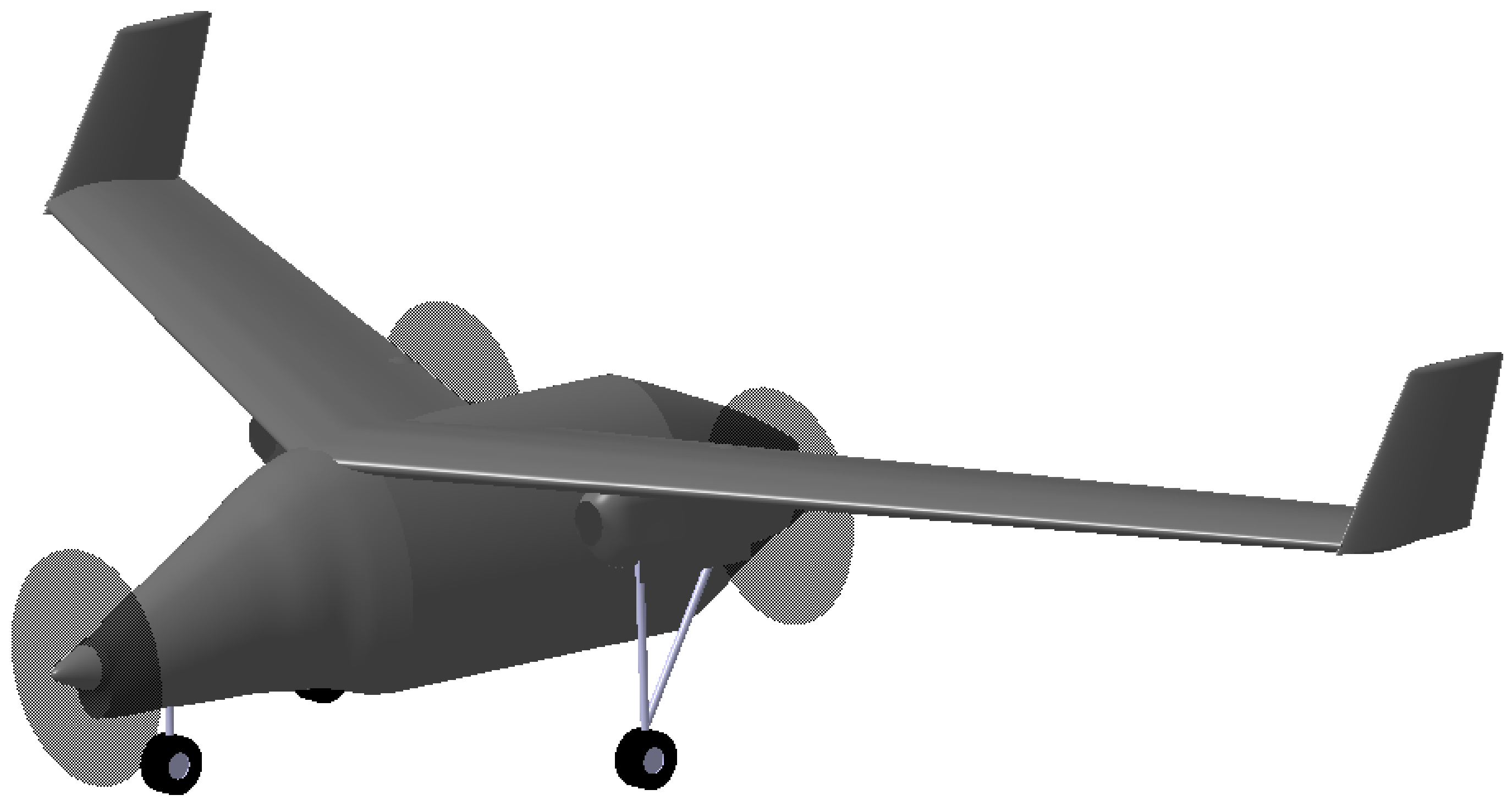

Introduction

This design project is in response to the American Institute of Aeronautics and Astronautics (AIAA) Request for Proposal (RFP) for an aircraft that is able to rapidly move an ISO standard 20 ft. shipping container with a total weight of 45,000 lbs to and from a combat zone. The container must be carried externally to the aircraft, and the aircraft must be able to operate out of short, unprepared airfields with little or no support equipment. The Allison T56 turboprop engine currently used on the Lockheed C-130 and P-3 aircraft must be used to maximize part and maintenance commonality. Speed and ease of loading are leading figures of merit in the design. With a very specific, well defined cargo, a tailless configuration was selected in order to minimize tail surface drag and unused fuselage volume. This design also allows for loading directly from the bed of a container truck with no external equipment required. In order to alleviate some of the traditional drawbacks of tailless designs and also allow for short field operations, longitudinal trim by means of wing flaps forward of the aircraft center of gravity were utilized. An iterative design process was used to optimize the design weight, fuel capacity, performance, and other pertinent criteria to meet all of the AIAA RFP design requirements.

Configuration and Approach

With such a well-defined cargo, the airframe can be very specifically tailored to the design mission. Though heavy, the container is not very long; thus, a traditional long, thin fuselage to contain the cargo would result in excessive empty space. In order to keep fuselage volume at a minimum, a tailless design was selected, negating the need for a large moment arm between the tail surfaces and the wing. The tailless configuration, however, is not without drawbacks. To perform short takeoff and landing (STOL) capabilities, powerful high lift devices are usually needed, but tailless aircraft usually cannot employ effective high lift devices without compromising trimming ability. Also, traditional tailless aircraft have needed to employ airfoil sections with reflex camber, which tends to decrease the maximum attainable lift values, in order to maintain static longitudinal stability. In [1], however, Kroo discusses that when appropriately designed, a stable tailless aircraft can employ an inboard flap that both provides the lift required for STOL operations and simultaneously trims the aircraft to higher angles of attack as well as normally cambered airfoil sections. This approach requires the wing to be at least moderately swept (~20° or more), with a large taper ratio (~0.7). To create an optimum elliptical lift distribution, generous washout (~-5° or more) must also be employed. This wing shape moves the aerodynamic center far enough aft that a deflection of the inboard flap generates a positive nose-up pitching moment even with adequate static margins. Thus, with greater flap deflection, the aircraft is trimmed at higher and higher angles of attack, as shown in Figure 1.

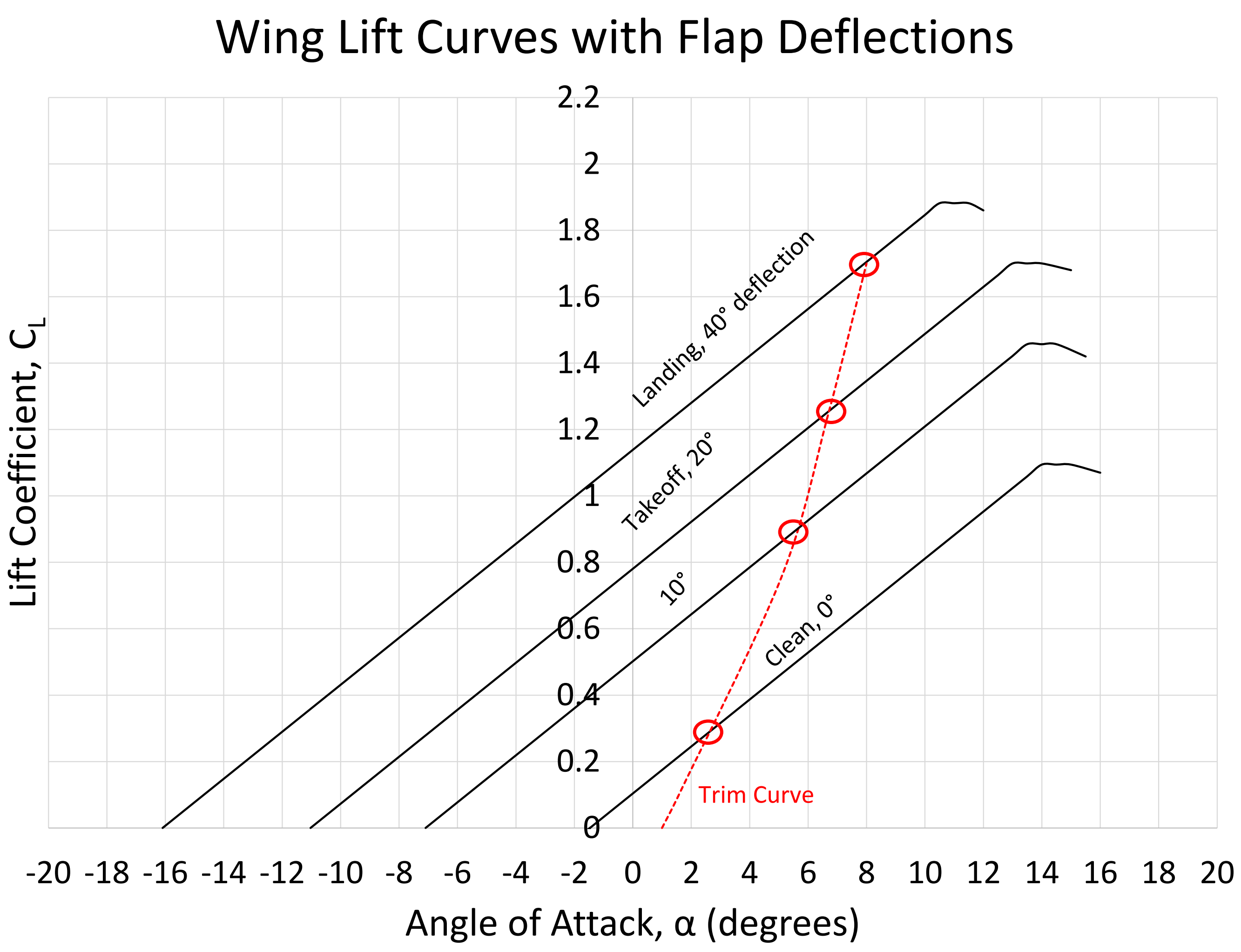

Figure 1: Trim lift coefficients and angles of attack at various flap deflection angles

Optimum Cruise Conditions and Mission Fuel

The AIAA requirements for the aircraft specify, at minimum, a 250 knot cruise speed at 23,000 ft altitude. Maximum cruising efficiency, however, may occur at higher and/or faster conditions than this specification. In [2], Torenbeek explains a method for determining highest cruise efficiency for turbine powered aircraft. This method takes into account the powerplant and aerodynamic efficiency to plot curves of Velocity/Fuel Flow Rate, with higher values corresponding with greater efficiencies. Since this aircraft is turboprop powered, it is limited to speeds less than approximately Mach 0.6, thus avoiding any onset of wave drag at transonic Mach numbers. With the efficiency curves plotted for three different aircraft weights corresponding with beginning of cruise, midcruise, and end of cruise, a number of cruise profiles were determined. Figure 2 is the cruise efficiency plot for the beginning of cruise. With a number of cruise profiles determined, the entire mission fuel was calculated by integrating the cruise efficiency over the distance travelled and also taking into account the fuel required to climb to the specified altitude. Of the several profiles considered, the most efficient path was a direct climb to 36,000 ft at a speed of Mach 0.55 followed by a step up to 37,000 ft midway through the cruise. This profile resulted in a fuel reduction of 6.5% over the minimum requirements of 250 knots at 23,000 ft altitude over a 1,000 nautical mile mission.

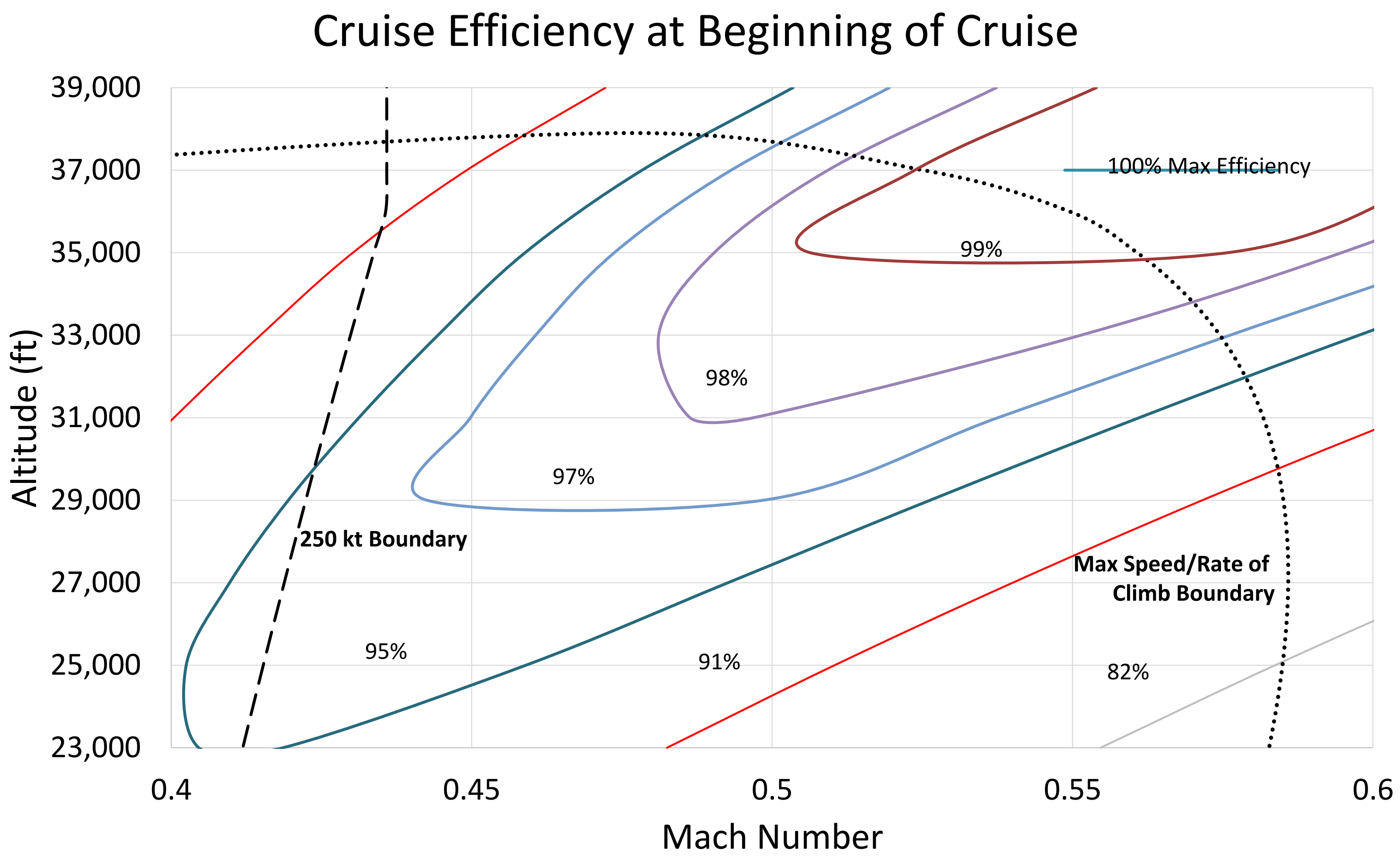

Figure 2: Cruise efficiency curves in the operational envelope

Operating Scheme

In order to rapidly load and unload cargo on unimproved airfields, the aircraft has a built-in ISO container spreader that can lift the container directly from a truck. The rear fairing of the aircraft swings away, allowing a truck to back in beneath the aircraft. Once in position, the battery-operated spreader lowers, locks into the container with traditional top-mounted twistlocks, and lifts it into proper position. Once in position, an aerodynamic fairing is extended beneath the container. Note that the sizes of the aircraft behind the cockpit area are merely aerodynamic fairings with no load-bearing ability. The tires or the aircraft are optimized for low pressure in order to operate on very soft fields a California Bearing Ratio (a measure of soil firmness) as low as 4. The landing gear is sized such that even the tallest container trucks are low enough to fit underneath the built-in spreader in the aircraft. Thus, in normal operation the aircraft needs no outside loading equipment and can operate a full mission only needing a refueling. With the aerodynamic fairings present, the aircraft can also operate without a container present, increasing its range to over 2,200 nautical miles.

Conclusions

Though a tailless configuration has never historically been used for a large transport aircraft, this design demonstrates that it is not only possible, but very efficient in the case of a well-defined, relatively short cargo. The aircraft need not be held back by the usual drawbacks of tailless aircraft, however, since a properly designed wing allows the use of high lift devices while still maintaining stability and trim. This approach has never been used on a large aircraft, but future designs may benefit from the advantages shown. Among other results, the most efficient cruise profile is an initial climb to 36,000 ft. Though more fuel is burned during the climb, the fuel saved during cruise makes up the difference. The very specific mission specified by the AIAA RFP lead to a very unique design that meets all of the requirements.

References

[1] Kroo, Ilan. "Design and Development of the SWIFT - A Foot-launched Sailplane." 18th Applied Aerodynamics Conference (2000): n. pag. Web.

[2] Torenbeek, Egbert. Advanced Aircraft Design: Conceptual Design, Technology and Optimization of Subsonic Civil Airplanes. West Sussex: Chichester, 2013. Print.