Aerodynamics of the Q-200/Tri-Q-200: Part 2 – Modeling Results

Part 2 (of 3) of a follow-up to my 2009 study discussing Q-2 decalage (Q-Talk 138). This study focuses on aerodynamic computer modeling of the Q-2 tandem wing configuration and comparison of those models with flying aircraft. -- Jay Scheevel, Grand Junction, Colorado

Q-200 Flight Envelope Modeling

The underlying details concerning modeling methods and assumptions for the models discussed in Part 2 (this part) of this study are summarized in Part 1. If any concepts or methodology are unclear, please review the discussion in Part 1.

The goal in this part is to describe as much of the flight envelope as possible, including takeoff and landing. This includes varying control inputs and their influence on the resulting flight characteristics of both the Q200 and Tri-Q200 when calibrated to flying aircraft. As outlined in Part 1, the modeling procedure employs Javafoil to compute the flight forces resulting from the wing surfaces and using spreadsheet calculations to incorporate all drag moments including landing gear drag. Javafoil is appropriate for computing stable/equilibrium flight, so generalization of model results to dynamic flight, including rapid vertical accelerations and decelerations, or abrupt control input changes is not appropriate. Limited analysis of smooth transitions based on the equilibrium models may be justified, so limited discussion of smooth transitions to landing and takeoff is included in this study.

The study includes models of flight in an unbounded air mass and flight in ground effect. Understanding how ground effect impacts flight behavior is critical to understanding landing and takeoff performance of the Q-200/Tri-Q200 configurations. Ultimately I focus on the Tri-Q200 because that is the model that I am building, however ground effect modeling also applies to conventional Q-200 design and is reviewed completely in this study. The most rigorous flight test data that is available (used for model calibration) was collected in QAC's prototype Q-200 N81QA, the original Q-200 tail dragger. A complete evaluation of the tail dragger Q-200 behavior is a prerequisite for analysis of the Tri-Q200. Flight test data is used to calibrate the model and quantify real world drag for both the Q-200 and the Tri-Q200. Once calibrated, the models are used to compare the flight characteristics of the two configurations in detail. The two landing gear variants differ as a result of both drag and lift forces primarily because the Tri-Q200 main gear's drag and lift components differ significantly from those of the original Q-200 gear design.

Part 3 of this study elaborates further on both variants (Q-200 and Tri-Q200) through analysis of the flights documented by point-of-view (POV) videos that have been posted to the web. As one might expect, landing and take-off behaviors of each design also differ because the Tri-Q200 must rotate in order to take off, whereas the conventional Q-2/Q-200 takes off essentially from a 3 point stance.

The Q-200 Flight Envelope

Figure 1 is a graph containing a series of colored curves which are generated by the calibrated model of the Q-200. Each colored curve represents the flight profile for a different decalage configuration. Any point on each colored curve represents an equilibrium flight condition where forces of both canard and wing (lift, drag and moment) combined with non-wing drag moments result in stable and level flight. The aircraft gross weight (900 pounds) is applied as a vertical force located at fuselage station (FS) and water level (WL) corresponding to the center of gravity

(CG) of the aircraft. Each colored curve represents all possible combinations of elevator deflections and alphas (~AOA) that result in stable equilibrium flight for that decalage and the listed loading condition. The vertical axis of the graph is alpha, and the horizontal axis is elevator deflection. The black contour lines are lines of constant airspeed (CAS), each marked with the corresponding CAS in MPH. These CAS contours are in increments of 5 MPH with the thick contours representing 100, 150 and 200 MPH. The point where each black airspeed contour intersects a colored curve is the point where equilibrium flight conditions correspond to that CAS, alpha and elevator deflection. For example, consider the light green curve (zero decalage). The 150 CAS contour intersects the green curve at elevator deflection of +2 degrees and alpha of -2 degrees resulting in level equilibrium flight if all those conditions are met. The yellow stars on this graph represent the reported elevator/CAS combinations for flight tests in the prototype QAC Q-200 N81QA and plot on top of the yellow curve corresponding to the model results for decalage of minus 1.

<u>The Calibration of the Model to Flight Tests</u>

Figure 1 displays the model results for a CG of FS=44" and a GW of 900 out of ground effect. The model incorporates both induced drag moments (caused by the lifting surfaces) and "non-wing" drag contributions (parasitic drag, form drag, skin drag, etc.) which are caused by a combination of landing gear layout, fuselage and tail geometry. Induced drag from the wings is modeled directly by Javafoil, but the non-wing drag must be estimated and calibrated directly to flight test data from real aircraft. In order to estimate non-wing drag, I use an alpha-dependent drag moment arm model to which I apply an airspeed-dependent drag force (constant drag coefficient). The drag arm is adjusted to cause the modeled elevator deflection/airspeed pairs to match the flight tests (see more explanation below, under the heading '*Non-wing Drag Estimation*').

The flight test data used for calibration of the Q-200 model was obtained by Michael Huffman. Michael was a Quickie Aircraft Corporation (QAC) regional dealer in the early 1980's, and at his request in 1983 was allowed by QAC to conduct independent flight tests in the Q-200 prototype (N81QA) at QAC's facility in Mojave. His test flights were conducted after QAC had converted and tested the new LS-1 canard. Huffman's detailed report includes data tables where he records elevator deflection vs. airspeed values for equilibrium flight (out of ground effect). He also recorded climb and glide performance numbers for several flights. These flight tests enable me to match my Javafoil models to the the actual airframe drag response over a wide range of airspeeds and elevator deflections.

The yellow stars posted in Figure 1 represent the measurements from Huffman's report. These points overlay the "minus 1" decalage curve (yellow). The flight tests were conducted at a weight of ~900 pounds. I estimate the CG of FS 44" based on his description of loading used for flight tests. In order for modeling to properly match the flight test observations from N81QA, the decalage of minus 1 (the yellow curve in Figure 1) from the Javafoil modeling must be matched to the flight test data (yellow stars) in order to be accurately calibrated.

By definition, a "plans-built" Q-200 has a decalage of zero (the light green curve in Figure 1), so why is the flight test data matching the calibrated model for a decalage angle of minus 1? This is because analysis of historical photos of N81QA from approximately the same date that Huffman performed his testing shows that N81QA has a decalage angle of minus 1. Despite the expectation that the prototype would have a decalage of zero (matching the QAC plans), the photos show that N81QA actually had a decalage angle of minus 1, meaning the main wing was one degree lower angle than the canard than that specified by to QAC plans. Whether this configuration change was intentional or not, I do not know, but I have confirmed this decalage based on several sets of photos of N81QA taken at about the same date as the flight tests. I have not found any plan changes, builder tips, or instructions from QAC literature recommending that the builder should alter the LS-1 canard or wing angles from those dictated by the level lines in the Q-200 plans. There was an earlier recommendation from QAC in Quickie Newsletter 14, p.4, July, 1981 to increase the canard angle by 1 degree (which would result in a decalage of minus 1), but this recommendation was issued prior to the creation of the LS-1 canard, and clearly was intended to apply to Q-2's with the GU canard. The mention of a revised canard angle recommendation was never included in LS-1 canard installation instructions. Perhaps the QAC recommended change originally intended for the GU canard was also intended to apply to the LS-1 vis-à-vis on N81QA, but a clear recommendation, specifically applying to the LS-1 was apparently never published by QAC.

Figures 2 and 3 are the documentary photographic evidence of the minus 1 decalage configuration on N81QA. Figures 2 and 3 are extracted from the same photo showing QAC's Q-200 prototype (N81QA) as photographed for a 1983 magazine article. The photo was taken the same year that the flight test data was collected by Huffman, so it can be safely assumed that the plane had this configuration when it was flight tested by Huffman. Figure 2 shows N81QA's canard root. I have overlain the BL15 LS-1 from the QAC-plans template rotated 8 degrees (leading edge up) to match the canard root profile in the photo. Figure 3 is a detail of the main wing from the same photo. In figure 3, the BL100 Eppler-1212 QAC template is rotated 7 degrees leading edge up to match the wing tip in the photo. Since the canard template requires 8 degrees of positive rotation to match the photo and the wing template requires only 7 degrees of positive rotation to match the same photo, then N81QA must have a decalage of minus 1. Keep in mind that the appropriate BL template was used for this analysis, so I have accounted for any washout angle according to the plans. The photo in Figure 2 also shows that N81QA has an unloaded ground angle of attack of about 8 degrees and that the firewall is about 0.5 degrees positive relative to the canard.

An alternate plot of the model results from Figure 1 is shown in Figure 4. The graph in Figure 4 plots airspeed vs. elevator deflection for each decalage with flight data for N81QA is posted as yellow stars. The yellow shaded region in both Figure 1 and Figure 4 represents the high speed flight region. In this region, the aerodynamic lift and combined pitching moments may exceed the pitch authority of the elevator, so flight could become uncontrollable. Any flight in this region is ill advised because recovery may be difficult or potentially impossible. The QAC recommended Vne of 200 MPH IAS for the Q-200 appears to be very safe regardless of decalage. A few Q-200 pilots have reported testing their Q-200's to IAS as high as 220 MPH. To my knowledge there have been no reports of high-speed controllability issues in the Q-200 with the LS-1 canard reported.

Non-wing Drag Estimation

Induced drag force and pitching moments caused by the lifting surfaces are computed explicitly by Javafoil, but non-wing drag (parasite drag, etc.) is not computed by Javafoil and must be introduced into models using spreadsheet formulas. The non-wing drag parameters are chosen to augment the JavaFoil model lift and drag forces so as to cause the model to match the flight test data over the entire range of alphas and airspeeds.

I simplify the "trial and error" approach by dividing the task into two parts. First, I choose an appropriate fixed drag coefficient that is consistent with reported power/airspeed envelopes of typical flying Q-200's and Tri-Q200's. Once the drag coefficient is selected, drag force can be computed using the standard drag formula combined with the known wetted area of the Q-200. The wetted area is determined using a full 3D surface model of the Q-200 using specialized 3D modeling software.

To choose the value of drag coefficient, I match the observed engine's power curve to the corresponding reported airspeeds in level flight for a variety of power and airspeed combinations. The most complete summary available to me is in Huffman's flight testing of N81QA, but those numbers are consistent with reports from other Q-200 pilots over the years. For level flight, total drag force (both induced and non-wing) is balanced by total engine power dissipation in the form of thrust. The most sensitive airspeeds for evaluating the non-wing drag coefficients are in the upper airspeed range where drag forces are the greatest and total engine/prop power output is well known.

With a power setting of 2600 RPM and manifold pressure of 22.8" Hg (standard atmospheric conditions), Huffman reports that N81QA achieved a level airspeed of 163 MPH CAS. N81QA demonstrated a level high speed pass of 185 MPH CAS at 2850 RPM (no reported manifold pressure). N81QA is powered by a Continental O-200 with a fixed pitch propeller (no pitch value reported). The engine maker's published data for the Continental O-200 with fixed pitch and standard prop-load indicates 83 horsepower (HP) at 2600 RPM. Extrapolation of the manufacturer's power curve to higher RPM's yields approximately 120 HP at 2850 RPM.

Applying a parasite drag coefficient of 0.011 to a total wetted area of 155 square feet and adding this drag force to the Javafoil model's induced drag in level flight (with decalage -1) requires 80 HP to achieve 160 MPH CAS. The same model requires 119 HP to achieve 184 MPH CAS. These power and airspeed pairs are close enough to the N81QA flight test values that a non-wing drag coefficient of 0.011 can be considered a good match between N81QA and the model.

With a fixed drag coefficient established, the computed drag force is applied to the airframe via a moment arm (drag moment). The arm is an imaginary lever of some length that is normal to the thrust line whose torque is applied at the aircraft's center of thrust. The arm has a variable length that is a function of alpha. The magnitude of the drag force is computed from the modeled airspeed and is applied to an appropriate arm length that forces the Javafoil model to match the flight test data. The physical significance of the drag arm can be thought of as the off center of force caused by all non-wing drag elements. In the Q-2 design, these drag elements are dominated by the landing gear placement, which is below the canard. So in this sense the arm would be expected to be negative (below the thrust line). The fuselage/empennage plays a more significant role at higher alphas where the airflow is at angles to the long axis of the fuselage.

When the drag moment arm and the drag force are non-zero (any non-zero airspeed), there is a pitching moment applied to the airframe. Negative arm values (arm is below the thrust line) causes a nose-down pitching and positive arm values cause nose-up pitching. The drag force is computed from airspeed for each alpha. To match the model to the flight data, the arm is varied until the model achieves a match to the flight test data. Once a match is achieved for every airspeed/alpha, the alpha vs. arm function for the model is determined and the model is considered a proxy for true aircraft response.

Figure 5 is a graph of the non-wing drag moment arm (as a function of alpha) that causes the Javafoil model to match the flight test data for N81QA. Note that the moment arm increases (becomes less negative) with increasing alpha because the canard rotates nose-up, bringing the landing gear closer to the thrust line. The drag profile of the fuselage also changes with alpha. At about 6 degrees alpha, all drag elements essentially align with the thrust line. In contrast, at zero degrees alpha (higher airspeed), the drag arm is about 30 inches below the thrust line. This combination causes the airframe to pitch forward significantly at high airspeed.

The moment arm model shown in Figure 5 is applied to all decalage models, since the arrangement of non-wing drag elements is the same for all decalage values. Each of the colored curves in Figures 1 and 4 have the same drag moment arm model applied.

Implications of Modeled Drag Moments to Flight Characteristics

Because the drag moment arm is essentially negative (center of non-wing drag is below the thrust line), the non-wing drag causes nose-down pitching tendency that increases significantly with increasing airspeed. At very high speeds, the pitching moment caused by drag may overpower the elevator pitch authority, resulting in an unrecoverable high-speed dive/tuck. Fortunately, the airspeed at which this could possibly occur, at least according to the models, is quite high (in excess of 220-240 MPH CAS), so this is an airspeed that is easily avoidable.

A positive side effect of the drag-induced forward pitching in the Q-200 is that as airspeed increases, the drag moment tends to “unload” the main wing and increasingly load the canard. In the high speed cruise, the main wing provides essentially no lift or possibly even a small negative lift. This effect may be partially responsible for the very efficient high speed flight of the Q-200 because induced drag is generated only by the wing area of the canard. At high cruise airspeeds, essentially only half of the total wing area is generating induced drag. Alternatively, at low speeds and higher alpha, both wings generate lift, so relatively slow speed flight is possible without the need for flaps.

Total Airframe Lift-to-Drag

Calculation of a total airframe lift to drag (L/D) value enables one to determine the minimum glide angle (power off), maximum climb angle and maximum climb rate for the model. These model numbers can be compared to flight test data to validate the accuracy of the model.

Figure 6 shows the modeled L/D vs. CAS for all modeled decalages using N81QA drag moment model. Not surprisingly, the maximum lift to drag for the total airframe occurs at the lower end of the airspeed range where both canard and wing are contributing. The optimum L/D vs. airspeed depends on decalage as shown for each colored curve. The L/D for a decalage=minus1 (yellow curve) occurs at 77 MPH CAS This is consistent with the reported minimum descent rate of 625 fpm at IAS of 80 (CAS ~77 MPH) from the N81QA flight test data. Maximum L/D values vary between 11.5 and 12.6 for various decalage angles.

Figure 7 shows power off glide angle vs. CAS. The minimum power off glide angle according to the model is 4.5 degrees, or 12.5:1 glide ratio. The minimum descent rate reported for N81QA was 625 fpm at IAS of 80 MPH (CAS ~77 MPH). This corresponds to 5.1 degrees glide angle or a 11.3:1 glide ratio. The Javafoil model indicates a glide angle of 4.8 degrees at 77 MPH CAS (11.9:1 glide ratio). This is a reasonably close match between model predictions and flight test data (which may include some effect of thermals at Mojave, during testing).

Power vs Airspeed for Q-200

Figure 8 compares the range of airspeed to power throughout the upper end of the airspeed envelope. The model results show that a decalage of -2 is the most efficient with respect to power vs. level airspeed, but there is comparatively little difference between curves for all decalage configurations. Only about 5 MPH range exists for any given power setting over the entire range of decalage from -4 to +3.

Flight in Ground Effect

Flight in ground effect has a significant impact on the Q-200 flight behavior. Elevator deflection, alpha, and airspeed (CAS) relationships vary significantly when in ground effect. The Q-200's two flying surfaces (main wing and canard) each have a unique contribution when in ground effect. The canard is more highly impacted by proximity to the ground than is the main wing, both because of the canard's higher wing loading and its more immediate proximity to the runway. However, the ratio of ground effect on each wing changes as the aircraft pitches up (alpha increases). With increasing pitch, the ground effect on the canard decreases, while the ground effect on the main wing increases. The combined effect reduces the maximum achievable alpha in ground effect significantly below the maximum alpha that is achievable when flying out of ground effect.

For modeling purposes, ground effect models assume an altitude above the runway consistent with the Tri-Q main gear being in contact with the runway (such as during taxi, rotation, landing and/or takeoff). The nose gear may or may not be in contact with the runway depending on rotation and taxi alpha. In this sense, the model assumes the maximum possible ground effect for any given alpha. The geometry of the wings relative to the ground are similar for both Q-200 and Tri-Q-200, so the Javafoil model is considered applicable to both configurations. Because of the landing gear differences between the tail-dragger and tricycle configurations, and because the Tri-Q200 must rotate for takeoff, takeoff and landing behavior of the two designs is quite different. Consequently, the behavior of each design will be discussed separately below.

Q-200 in Ground Effect

Figure 9 (ground effect model) shows the same data as Figure 1 for the Q-200. The yellow star flight test data points (no ground effect) are plotted Figure 9. The offset between the yellow stars and the yellow curve demonstrates the magnitude of ground effects limit on alpha at any given airspeed and elevator setting. For example, 68 MPH level flight in ground effect results in an alpha of a little over 6.8 degrees. Out of ground effect, 68 MPH level flight corresponds to an alpha of 9.7 degrees. 68 MPH CAS is near the pitch buck airspeed both in and out of ground effect, yet alpha is nearly 3 degrees lower when in ground effect.

In summary, with all other things being equal, ground effect causes the maximum alpha (~max AOA) to be significantly lower. For the same reason, significantly more (down) elevator deflection is required to maintain a given airspeed/alpha combination when in ground effect. This means that elevator is essentially less effective in ground effect, and this is significant when landing. Ground effect contributions are more pronounced at lower airspeed, as shown by the large separation between the stars (no ground effect) and the yellow curve in Figure 9.

Figure 10 is a different comparison of the non-ground effect flight test data (stars) to the ground effect model's yellow curve. This illustrates the impact on minimum level airspeed both in and out of ground effect for a decalage of -1. The other colored curves are model results for the other decalage values in ground effect.

Figure 10 also shows that the minimum achievable airspeed in ground effect is higher than out of ground effect. This is because of a reduction in induced drag on both wings when in ground effect. Elevator deflection (pitch sensitivity) for a given airspeed in ground effect is significantly reduced. A level speed of 70 MPH CAS out of ground effect requires about 7 degrees of elevator deflection, but in ground effect this same level speed of 70 MPH requires 15 degrees of elevator deflection, more than twice that required out of ground effect.

In summary, significantly more elevator is required to maintain constant airspeed in ground effect, while pitch sensitivity is lessened. When entering ground effect, the Q-200 will experience a slight acceleration, accompanied a pitch reduction, even if elevator deflection is increased. When flying into ground effect, just prior to flare, this behavior might be counter-intuitive to pilots more familiar with conventional single-winged aircraft.

To understand this phenomenon more fully, we can examine the pressure distribution on the wing and canard surfaces. Figure 11 contains two vertical cross-sections (parallel to BL15) showing the pressure distribution around the Q-200 wings in level flight. The bottom cross section is in ground effect, and the top section is out of ground effect. The pressure distribution is depicted by color. The "cooler" colors represent reduced pressure and the "warmer" colors represent increased pressure. Ambient air pressure is shown in yellow. Streamlines are shown in blue.

The pressure values in immediate contact with the wing and canard surfaces are responsible for generating the flight forces. Figure 11, shows that pressures on the wing and canard surfaces are very similar for both upper and lower sections, confirming that forces are also very similar. In the lower section (in ground effect), wings are flying 3 degrees lower alpha than when not in ground effect. Both sections have identical 17 degree elevator deflection. Figure 11 illustrates the physical reason why flight into ground effect while holding a fixed elevator setting causes the angle of attack to be reduced significantly.

To counter this downward pitching tendency when entering ground effect, elevator deflection must be significantly increased. A pilot should exhibit caution during final flare, as there may be a risk running out of elevator in ground effect while trying to hold or increase pitch (alpha).

As shown in Figure 9, the maximum alpha angle of around 7 degrees in ground effect is consistent with real-world observations on actual flying Q-200's. According to the Javafoil models, ground angle of 7-8 degrees at take-off is consistent with a smooth 3-point takeoff. Taking off and landing from a three point stance at about 7 to 8 degrees alpha at minimum airspeed (below 70 MPH CAS) is consistent with the QAC literature for N81QA. Alpha values in the range of 7-8 degrees have also been reported by several Q-200's pilots for both take-off and landing in aircraft that have measured decalage angles between 0 and -1 degrees. This is consistent with flying Q-200's measured on "point of view" POV videos created by various Q pilots that are analyzed in Part 3 of this study.

Hypothetical Landing Scenarios for the Q-200 Based on Modeling

A few hypothetical transition-to-landing scenarios can be investigated using a modified version of Figure 9 (as in Figure 12).

Suppose the prototype Q-200 (decalage -1, GW 900 lbs., CG FS 44") is flying straight and level out of ground effect at 88 MPH CAS, zero elevator deflection and alpha of 4 degrees. According to the model, the aircraft would stay level provided the engine was imparting about 20 horsepower. With reduced power the aircraft would descend (about 36 fpm for each 1 HP power reduction). Let us suppose that the aircraft descends into ground effect while maintaining the same airspeed and zero elevator deflection. This starting point is represented by the top of vertical blue dashed arrow in Figure 12.

The vertical blue dashed arrow shows what happens if the elevator deflection is held constant at zero degrees after entering ground effect. In this case, the aircraft would pitch forward while accelerating to well over 100 MPH. Keeping the elevator deflection unchanged at zero, level flight requires alpha to drop from 4 to less than 1 degree and CAS would increase from 90 to almost 120 MPH. Power setting would need to double from 20 to more than 40 horsepower. These are large changes that would not be instantaneously achievable without loss of altitude. Such an approach would be counterproductive if one was trying to land the airplane. Clearly, holding the elevator constant at 0 degrees, while advancing the throttle, would NOT be the appropriate response for a pilot who is attempting to put the plane on the runway, so the vertical blue dashed arrow is not a viable path to a landing.

A more likely approach is represented by the inclined dashed blue arrow in Figure 12. In this case the airspeed is held fairly constant between 88-90 MPH CAS as the plane enters ground effect. When in ground effect, the elevator deflection is increased from 0 to 4.5 degrees, the aircraft will pitch forward slightly from 4 to 3.3 degrees while the power required for level flight will decrease from 19 to 17.4 HP with airspeed staying around 88 MPH. If power is not reduced slightly at this point, the plane will accelerate slightly or start slowly climbing depending on how much elevator is applied. What would the pilot do at this point? Probably chop the power and pull back on the stick to bleed off airspeed and start the flare. This transition is represented by the curved dashed blue arrow in Figure 12, illustrating the bleeding off of airspeed, increasing pitch then touch down at alpha around 6 degrees and an airspeed of 74 MPH CAS with power at 12 HP or less.

Another alternative is shown by the horizontal blue dashed arrow in Figure 12. In this case the pilot increases elevator in order to hold the pitch constant as the aircraft enters ground effect at 88 MPH and 4 degrees alpha. When level in ground effect, the speed drops off from 88 to 82 MPH CAS, and power needs to be reduced from 19 to 15 HP (or less, in order to bleed off airspeed). The horizontal blue dashed arrow would join the curved dashed arrow during flare and landing as in the previous scenario.

The blue arrow scenarios tell us what could happen when approaching at higher airspeeds, the best landing scenario probably lies somewhere between the inclined and the horizontal dashed blue arrows. The first scenario of holding a constant elevator deflection, as represented by the vertical dashed arrow in Figure 12, would naturally be avoided.

What if the pilot enters ground effect at a lower airspeed maintaining a higher pitch (alpha angle)? Let's examine that possibility with the dashed red arrows on Figure 12. Starting at 72 MPH CAS, and alpha of 7 degrees out of ground effect, the pilot decides to hold the elevator constant at 6 degrees (vertical red-dashed arrow). The aircraft upon entering ground effect will pitch forward from 7 to 4 degrees alpha, and airspeed will increase from 72 to 83. For level flight, the power would need to increase slightly from 14.4 to 15 HP. The aircraft would then touch down with a "wheel landing" at an alpha of about 4 degrees and then slow until the tail came down around 70 MPH.

What about a slow approach while attempting to hold a constant alpha of 7 degrees when entering ground effect (horizontal red dashed arrow)? As soon as the aircraft enters ground effect it starts to slow down to 70 MPH or below. Even with full stick deflection, at this low speed the canard will be overpowered by the wing and the pitch will drop abruptly. In this case, the risk of a bounce on touchdown goes way up.

A more appropriate path to landing after approaching at a low airspeed is shown by the inclined dashed red arrow on Figure 12. This path requires less aggressive use of the elevator, increasing elevator deflection from 6 to only 9 degrees when entering ground effect. The aircraft will pitch forward a degree or two (7 to 5.5 deg. alpha) while maintaining airspeed near 77 MPH (requiring a slight increase in power). At touchdown, the power is chopped and the inclined red dashed arrow joins the curved blue dashed line as in the previous scenarios.

Summarizing the landing scenarios (for decalage of -1):

1. Higher airspeed (88 MPH CAS) flight entry to ground effect (88 MPH CAS) presents the pilot with the more intuitive options of chopping power greater freedom for more aggressive elevator input and the comforting feel of a very significant increase in pitch prior to touchdown. Any disadvantage lies by the fact that because the Q-200 is a very low drag airframe, especially while in ground effect, bleeding off airspeed prior to touchdown requires a lot of runway and a patient hand on the stick to avoid premature flare. If runway length is not an issue, entering ground effect with more airspeed is probably the best approach with the most options, at least according to the models.

2. Lower airspeed (77 MPH CAS) flight into ground effect requires careful elevator control. Upon entering ground effect, the pilot must allow the aircraft to pitch forward slightly and accelerate slightly (with quick addition of power to slow the descent, while holding airspeed). This is accompanied by a very small increase in elevator and only a subtle increase in pitch during flare. The clear advantage of this method is afforded by the lower airspeed throughout the landing process. Because of this, the process would require less runway. A disadvantage is that the whole process requires higher alphas throughout, from final approach to touchdown. This restricts the pilot's forward vision on final approach. Also, the pilot has to be content with much more subtle pitch control and elevator input to avoid over flaring too early leaving little room for error.

Variations in decalage, gross weight, center of gravity, and gear configuration (see the Tri-gear landing and takeoff discussion below), obviously will vary these results, but this hypothetical discussion, based on the models potentially provides some insight into approach and landing strategies for the Q-200.

Tri-Q2 Fight Envelope Modeling

The physical layout of the Tri-Q200 (wing and canard) is not significantly different than for the Q-200 tail dragger, however flight behavior of the Tri-Q200 differs from the Q-200 in cruise pitch and airspeed, but also to a lesser degree during flight in ground effect.

To my knowledge, there is no rigorous flight test data for the Tri-Q200 like that provided by Huffman for N81QA (Q-200). Consequently, the data available for the calibration of Tri-Q200 models was extracted by detailed analysis of multiple point of view (POV) videos posted online for flights of Tri-Q200's and from word of mouth data provided by conversations with Tri-Q pilots. Detailed analysis of the videos is presented in Part 3 of this study, but the relevant data extracted from the Tri-Q200 videos is used in in this part to provide CAS versus alpha modeling constraints for the Tri-Q200 and also to make a quantitative comparisons between the Q-200 Tri-Q200 design variants. Because elevator deflections cannot be reliably determined from the Tri-Q200 videos, my calibrations of the Tri-Q200 models are based on airspeed versus alpha only data only.

The primary Tri-Q200 videos used for calibration of the model are from flights of a Tri-Q200 built in the late 1980's as a Tri-Q with LS-1 canard and later re-engined with a Continental O-200A. The aircraft is N585SY which belonged to Jean Paul Chevalier when I measured and analyzed it, but has since been sold to a new owner. In the videos used for analysis, the aircraft is flown solo with loading similar to the loading that N81QA had during Huffman's flight testing, so it is a good candidate for direct comparison to N81QA.

CAS values for N585SY in the videos were derived from ground speed which can be measured from the video by comparison with ground references whose relative distance, one from the other is measured accurately using Google Earth. Correction of measured groundspeed to CAS are made by assuming no wind, correcting for density altitude, estimated temperature and humidity based on the date and location the video was filmed. Consequently, these speeds are approximate, but consistent. On occasion, a clear view of the airspeed indicator on the panel is visible, allowing a rough check between indicated airspeed (IAS) and the CAS values computed directly from the video. In these cases, they match.

Alpha values are measured by knowing the alpha while taxiing (measured in person on the actual airframe in taxi position). The taxi angle is the initial reference, allowing calibration of a graphical angular scale superimposed on "screen capture" frames from the videos. The superimposed angular scale is calibrated from the known angular separation between visible features on the airplane, as seen from the camera's point of view. Features such as wing/cowling/windscreen edges provide known angles with respect to a known camera position, usually on the seatback bulkhead. Using the measured angles, a calibrated scale is created by subdividing the known angles. The calibrated scale allows measurement of alpha during various phases of flight by comparing the scale against the distant horizon (vanishing point) when the plane is flying level at a fixed airspeed. Calibrated screenshots can be seen in Part 3 of this study.

Wing incidence measurements for N585SY were performed on the actual aircraft using the precision incidence measurement tool described in my wing decalage study in QuickTalk issue 130. N585SY has a measured decalage of about -0.4 degrees. Recall that N81QA has a decalage of -1.0 degree for comparison.

N585SY also has a Gary Legare style T-tail trim device installed. The impact of the T-tail could not be measured by the methods used in this study, so there is uncertainty as to its impact in flight, but the flight characteristics of N585SY with the T-tail, do not appear to vary significantly from other Tri-Q200 videos in comparison with aircraft that do not have the T-tail. So for now, the effect of the T-tail is neglected.

Figure 13 is model data for the Q-200 showing alpha versus CAS. The N81QA flight test points are plotted as yellow stars. Tri-Q200 flight test data derived from videos for the N585SY is plotted as *blue* stars in Figure 13. The curves are the model data are for level flight out of ground effect.

There are significant differences between the blue stars and the Q-200 model which matches the actual Q-200 (N81QA) performance. There are similarly large differences between the blue stars and the yellow stars since the yellow stars are flight test data from the actual aircraft. The differences between the Tri-Q200's flight data and the Q-200 model cannot be explained by the small difference in decalage angle (-0.4 vs -1 deg.) between N81QA and N585SY. In fact, if this decalage was responsible, the more positive decalage value of the Tri-Q200 would dictate that the blue stars should plot below the yellow stars, not above. So clearly there are more dominate factors affecting flight behavior in the Tri-Q200.

The canard/wing layout of the Q-200 and Tri-Q200 is too similar to explain have significant effect differing only in the anhedral, or lack of it in the canard. So we must look toward non-wing causes for the observed differences. Javafoil models confirmed though analysis of Tri-Q200 videos seems to indicate that the landing gear layout (both layout and design) is responsible for the observed flight characteristic differences of the two design variants.

Tri-Q200 non-wing drag analysis

In order to compare the Q-200 and Tri-Q200 using the models, we must make an estimate of the non-wing drag coefficient and drag arm for the Tri-Q200 like we did for the Q-200. In the case of the Tri-Q200, airspeed (CAS) versus power data is not rigorously constrained by careful flight test data. However, historical reports of power and airspeed values for Tri-Q200's are fairly common. A review of available reports reveals that the Tri-Q200 is significantly slower than the Q-200, even when accounting for all other factors such as power plant and propeller.

One would suspect that non-wing drag for the Tri-Q200 is higher because of the tricycle gear and this would be the likely reason that the Tri-Q200 flies slower than the Q-200 counterpart, regardless of decalage. The average cruise CAS for the Tri-Q200 is routinely reported to be 10-15 MPH slower than for an equivalent Q-200. Most Tri-Q2's are powered with the Continental O-200, so engine choice can be eliminated as a factor. To match the model to the observed reduced speed of the Tri-Q200, we must increase the non-wing drag coefficient. A match is achieved by increasing the non-wing drag coefficient of the Tri-Q200 model to 0.017 (applied to a total wetted area of 158 square feet). This drag coefficient is 55% higher than that of the Q-200 N81QA (0.011). This said, the 0.017 drag coefficient is near the low end of reported drag coefficients for small general aviation aircraft, especially those with fixed landing gear.

As shown in Figure 5, the drag moment arm for N81QA (Q-200 tail dragger) is negative (below the thrust line) regardless of alpha. This is because of canard anhedral combined with the principal drag elements being the landing gear located at the ends of the canard are well below the thrust line. As discussed previously, the effect of a negative drag moment arm is to cause the Q-200 to pitch nose-down as a result of non-wing drag, especially at high airspeeds. In figure 13, the blue stars represent the flight test data for the Tri-Q200 derived from videos. The blue stars show that the Tri-Q200 flies at a higher than alpha for any given airspeed. This tendency becomes greater at higher airspeeds. The behavior suggests that the Tri-Q200 drag arm must be positive in order to cause the aircraft to pitch up rather than down. A positive drag arm does not make sense physically because it would indicate that the primary drag elements are above the thrust line, not below it. A positive non-wing drag moment on the Tri-Q-200 is counterintuitive and likely invalid for two reasons:

1. The gear legs and wheels on the Tri-Q200 are the most likely source of drag on the Tri-Q200. The landing gear is entirely located below the thrust line, and should result in a negative drag moment arm.

2. The Tri-Q200 has a drag coefficient that is 155% that of the Q-200's, so in comparison the drag forces on the Tri-Q200 should be higher for any given airspeed, which would make drag arm effects more impactful than on the Q-200. Since there is no difference in drag elements above the thrust line on the Tri-Q200 there is no element of the Tri-Q200 that can explain drag above the thrust line in comparison to the Q-200.

The only design difference of the Tri-Q200 relative to the Q-200 is the gear arrangement. Any differences in gear must be the cause of greater nose-up pitching tendency. Trying to accomplish this with drag arm modeling in the Tri-Q200 and this is clearly not physically reasonable, so we must look for another solution caused solely by the different gear design.

The most likely explanation lies in the effect of the wing-like behavior of the Tri-Q main gear leg. The Tri-Q fiberglass gear leg is essentially a symmetrical airfoil. It acts like a small wing. Average chord measurements made on my Tri-Q200 gear leg (installed per plans) reveal that the gear leg airfoil has a significant negative incidence relative to streamlines behind the canard.

This is demonstrated in Figure 14, where the Javafoil model streamlines are superimposed in white on photos of my airframe. The dashed red line is the extended chord line of gear leg airfoil. To highlight and measure the average chord line, two pieces of wood lath are clamped to the top and bottom surface of the gear leg and aligned parallel the centerline of the airframe.

The gear leg airfoil is negatively inclined to streamlines for all phases of flight, but this negative incidence is most significant at high airspeeds where the overall alpha values are low. The gear leg's negative incidence tends to "de-lift", meaning it produces down force which is applied aft of the overall center of lift. The gear leg de-lifting force opposes the lifting forces of both the canard and wing. The net effect of the gear de-lifting is to result in nose-up pitching tendency that increases with airspeed. This would seem to explain the tendency of the Tri-Q200 to fly at a higher than expected alpha.

The difference between the gear leg mean chord angle and the streamlines (relative wind) is significant. The greatest difference is at negative 13 degrees relative to streamlines near the outboard end of the gear leg and about negative 8 degrees near the inboard end of the leg as shown in Figure 15.

In summary, it appears that the main gear leg, acting as a de-lifting wing is the most likely physical explanation for the Tri-Q200 flying at higher than expected alpha relative to the Q-200, especially at higher airspeeds.

Modeling the Tri-Q Main Gear Leg

Based on the likelihood that the gear leg "airfoil" has a significant effect on the flight of the Tri-Q200, a Javafoil model was constructed which includes the aerodynamic effects of the gear-leg "wing". The Q-200 Javafoil model was altered by adding a small third "wing". The gear leg airfoil was only added to the inner "third" of the Javafoil models (outer two thirds remain the same as the Q-200 model, in order to simulate the effect of the limited span of the gear leg). The FS position of the gear leg in the model is the average position of the gear leg on the actual airframe, since the gear leg has a significant forward sweep. Figure 16, is the revised model (inner 1/3). The dashed line serves only to illustrate the angle of the extended gear leg chord. It is not part of the model.

Figure 17 (below) shows the Javafoil model alpha vs. airspeed (CAS) results for decalage values of 0, -1 and -2. Other decalage values (+3,+2,+1,-3 and -4) were not modeled. The effect of the gear leg is essentially the same as increasing the decalage angle by +1 degree. The blue stars represent the Tri-Q200 flight test data shown in Figure 13, and the yellow stars are the Q-200 flight test data.

The model also includes the non-wing drag coefficient of 0.017 (as determined above) for the Tri-Q200, whose drag force applied to a negative drag moment arm similar to that of the Q-200 model. The Tri-Q drag moment arm model (Figure 18) is negative for all alphas (meaning that the center of drag is below the thrust line), as expected for an aircraft with the gear legs extending below the fuselage.

The de-lifting behavior of the gear leg “wing” is sufficient to overpower the nose-down tendency of the drag moment arm, even though the non-wing drag forces of the Tri-Q200 are larger than that of the Q-200. The nose-up effect of the de-lifting gear leg ultimately is the dominant effect, causing the Tri-Q200 to fly at a higher alpha than its tail-dragger cousin. Figure 17 shows that the blue star “flight data” points nearly overlay the yellow curve (-1 decalage) for the model when the gear leg “airfoil” is incorporated in the model. Given uncertainties in the flight test data, the model result in Figure 17 is considered a close match to the flight tests (blue stars).

In summary, this model takes into account all aspects of the landing gear on the Tri-Q200 including drag below the thrust line aerodynamic de-lifting and induced drag forces caused by the gear leg airfoil. The model validates the concept that the main-gear leg’s negative incidence angle results in the observed differences in flight characteristics between the Q-200 and the Tri-Q200.

The main gear leg causes other side effects as well. In all flight attitudes, it opposes (subtracts from) the lifting forces of the other two wings. This effect forces the Tri-Q200 to have a lower effective lift coefficient than the Q-200. This is especially significant at higher airspeeds, when alpha is lower, meaning that the gear leg negative incidence is most impactful. The Tri-Q200 Javafoil model incorporating the gear leg can be compared quantitatively with the Q-200 model. At low airspeed (69 MPH CAS), the Q-200 lift coefficient (CL) is 1% higher than the Tri-Q200, so not much difference. At intermediate airspeed (120 MPH CAS), the Q-200 has 30% higher CL than the Tri-Q200, and at cruise airspeed (150 MPH CAS), the Q-200 has 50% higher CL than the Tri-Q200. This explains why the Tri-Q200 must fly at a higher alpha than the Q-200 for a given gross weight. The higher alpha is required in order to offset the lift penalty of the gear leg which is flying at a negative relative angle of incidence. In addition to the higher drag coefficient, the reduction in lift efficiency that increases with increasing airspeed appears to be a significant factor causing the Tri-Q200 to fly slower than the Q-200.

Takeoff of the Tri-Q in Ground Effect

It is no surprise that the Tri-Q200 and Q-200 also differ significantly in takeoff and landing characteristics. So far the modeling has focused on significant differences in flight characteristics, but those differences affect speed, efficiency cruise alpha. Takeoff and landing differences are more critical because the Tri-Q200 ground angle of attack (on tricycle gear) is significantly lower than the Q-200. This lower angle necessitates that the aircraft must have sufficient control authority in order to rotate “nose-up” to achieve flight. Rotation is not a significant concern for takeoff in the Q-200 because of its significantly higher taxi alpha.

The aerodynamic forces and moments in the Tri-Q200 must overpower moments resulting from gross weight and position of the landing gear in order for rotation to occur. In short, the weight on the nose gear must be overcome in order to rotate and takeoff. Once nose gear comes off the ground the aircraft can rotate to an alpha sufficient for takeoff. The balance of moments can change immediately upon take off for the Tri-Q200, when the main gear leaves the ground, and this usually requires significant elevator correction be made once airborne.

The lifting surfaces’ first task is to overcome the weight on the nose gear by applying an appropriate moment. The second task of the lifting surfaces (after takeoff) is to transition to balancing the CG and drag forces of the aircraft in level or climbing flight. The Tri-Q200 Javafoil model can be used to evaluate moments prior to, during rotation, and in flight during transition out ground. This can be done for a range of decalage values, elevator settings and airspeeds.

Figure 19 is a plot of alpha vs. elevator deflection in ground effect. It is similar to Figure 9, except that it applies to Tri-Q200. There is only one decalage curve shown (for decalage of zero: light green curve). This plot contains black contours representing airspeed. The point of intersection of the black contour with the light green curve, depicts the airspeed (CAS), elevator and alpha corresponding to equilibrium flight. There are also green contours on the right side of the plot. These green contour lines represent all conditions (elevator, alpha, CAS) that result in zero weight on the nose wheel (meaning rotation can occur). The number on each contour is the airspeed (CAS) corresponding to that contour.

Figure 20 is identical to Figure 19 with the addition of two hypothetical rotation and takeoff scenarios/paths. The scenarios apply to a Tri-Q200 with a decalage of zero. At a taxi angle (alpha) of 5 degrees, the aircraft would accelerate to 74 MPH CAS, then application of 14 deg. elevator deflection will cause the aircraft to take flight with no pitch change (blue dot). In the case where the taxi alpha is only 2 degrees (such as N585SY), then the plane would need to accelerate to 84 MPH CAS , then an input of 25 degrees of elevator would cause rotation to 3.8 degrees alpha followed by takeoff. Upon takeoff, the pilot would need to immediately reduce the elevator from 25 to 6 degrees in order to maintain level flight. If the elevator is not reduced then the aircraft would pitch up significantly and possibly settle back onto the runway. A change from 25 to 6 degrees of elevator is a large change so probably cannot be done instantaneously, so some pitching up would be expected by the pilot before finding equilibrium again. This pitch up is caused by the fact that there is still significant moment on the main gear at the time the plane leaves the ground, and aircraft attitude must be corrected when contact with the ground is lost. The difference in takeoff behavior is simply the result of taxi alpha. Because 5 degrees taxi alpha corresponds with level flight at 74 MPH, the plane can simply take off from 3 points. If the taxi angle is lower, like the 2 degree example, then the aircraft must achieve sufficient speed for the canard lift to overcome the weight on the nose wheel and rotate. This cannot happen until the aircraft reaches 84 MPH.

Figure 21 is similar to Figure 20 with the exception that it is specific to a decalage angle of minus 1. In the case of a taxi alpha of 5 degrees (blue dashed arrows), 25 degrees of elevator deflection will cause it to rotate from 5 to 5.2 degrees alpha and then takeoff at 78 MPH. An immediate elevator reduction to 7.5 degrees is required for level flight. Alternatively, if the plane were to accelerate to 80 MPH CAS at a taxi alpha of 5 degrees (blue dot), it would simply take off from a 3 point stance with 6.5 degrees of elevator and fly in ground effect remaining at 5 degrees alpha. In the case where the taxi alpha angle is 2 degrees (red dashed arrows), the aircraft would need to accelerate to 78 MPH CAS, then 25 degrees of elevator will cause the plane to rotate to 5.2 degrees alpha and take off. Immediate reduction of elevator from 25 to 7.5 degrees would be required to maintain level flight.

Figure 22 is similar to Figure 21. except this figure applies to a decalage angle of minus 2. If taxi alpha is 5 degrees, applying 25 degrees of elevator will cause the aircraft to rotate to 6.7 degrees alpha and then takeoff at 73 MPH CAS. An immediate elevator reduction from 25 to 11 degrees is required for level flight. In the case where the taxi alpha angle is 2 degrees, the aircraft would need to accelerate to 73 MPH CAS, then 25 degrees of elevator will cause the plane to rotate from 2 to 6.7 degrees alpha and take off then elevator to 11 degrees is required to maintain level flight.

The major effect of reducing the decalage angle is that it tends to facilitate take off at a lower airspeed with a correspondingly higher alpha. Doing so also requires smaller elevator adjustments after takeoff.

For all decalage values, lower taxi alpha angles require more aggressive rotation for takeoff. After takeoff significant elevator correction (forward stick) must occur quickly in order to prevent large increase in pitch immediately after takeoff. So, in general higher taxi alpha and more negative decalage aids takeoff performance.

Reflexor in Takeoff and Landing for Tri-Q200 in Ground Effect

The Javafoil model allows any “flap” configuration on any wing surface. So far in this study, only elevator deflections combined with different decalage variations have been evaluated, however adjustments can also be made in the form of a “flap” on the main wing. Doing so allows us to simulate the effect of aileron “reflexor” settings on the main wing.

For the Tri-Q200 we can evaluate the impact of the deploying the reflexor during rotation, takeoff, and landing. For modeling, the deflection of the reflexor is limited to the inner “third” of the wing, so as to approximate the limited span of the aileron/reflexor.

Figure 23 is similar to Figure 22, with the exception that is shows the Tri-Q200 (decalage -2) response in ground effect with the aileron reflexor set to 6 degrees trailing edge up. The impact of up reflexor on the takeoff behavior of the Tri-Q200 is dramatic. Comparison of Figure 22 and 23 reveals this significant difference. With the reflexor set to 6 degrees up, if ground taxi alpha is 5 degrees and elevator is deflected to 13 degrees at 66 MPH CAS, the nose will start to lift. Deflecting the elevator to 24 degrees will further lift the nose to alpha of 9.4 degrees and the plane will take off. After takeoff, no elevator correction is needed to achieve level flight (alpha remains at 9.4 degrees in flight). This means that there is zero moment on the main gear at the point of takeoff. Without the reflexor, the elevator correction required to transition from rotation to flight is large (elevator 25 to 11 deg.). The application of 6 degrees reflexor causes the takeoff alpha to be 2.7 degrees higher (6.7 to 9.4 deg. alpha) and this in turn causes the moment on the main gear to essentially vanish at takeoff in addition to allowing takeoff to occur at 66 MPH CAS, versus 73 MPH (no reflexor).

With a taxi alpha of 2 degrees, the rotation and transition to takeoff is very much the same as for taxi alpha of 5 degrees, but at 2 degrees taxi alpha, the nose will begin to lift with no elevator deflection at 66 MPH CAS. Even prior to takeoff, the application of 25 degrees of elevator will cause the nose to lift (zero weight on nose) when CAS is as low as 55 MPH. This behavior is beneficial in shortening the landing distance because the nose can be held off longer, adding air drag braking from the wings. Similarly, applying 6 degrees of up reflexor can minimize takeoff distance, since only 66 MPH is required to become airborne versus 73 MPH with no reflexor. If the pilot chooses to rotate and takeoff at speeds higher than 66 MPH CAS, elevator correction required for transition from rotation to flight is much less aggressive compared to the no reflexor case.

The primary differences between the 6 deg. and no reflexor case are as follows: For the case with 6 deg. of reflexor, the takeoff speed is 7 MPH lower and the takeoff alpha is 2.7 degrees higher. Lower take off speed is an improvement with reflexor thereby decreasing runway requirements. This may also be an advantage for soft field takeoff. One disadvantage with the reflexor is that the higher alpha during takeoff and landing reducing the over-the-nose visibility.

End of Part 2.

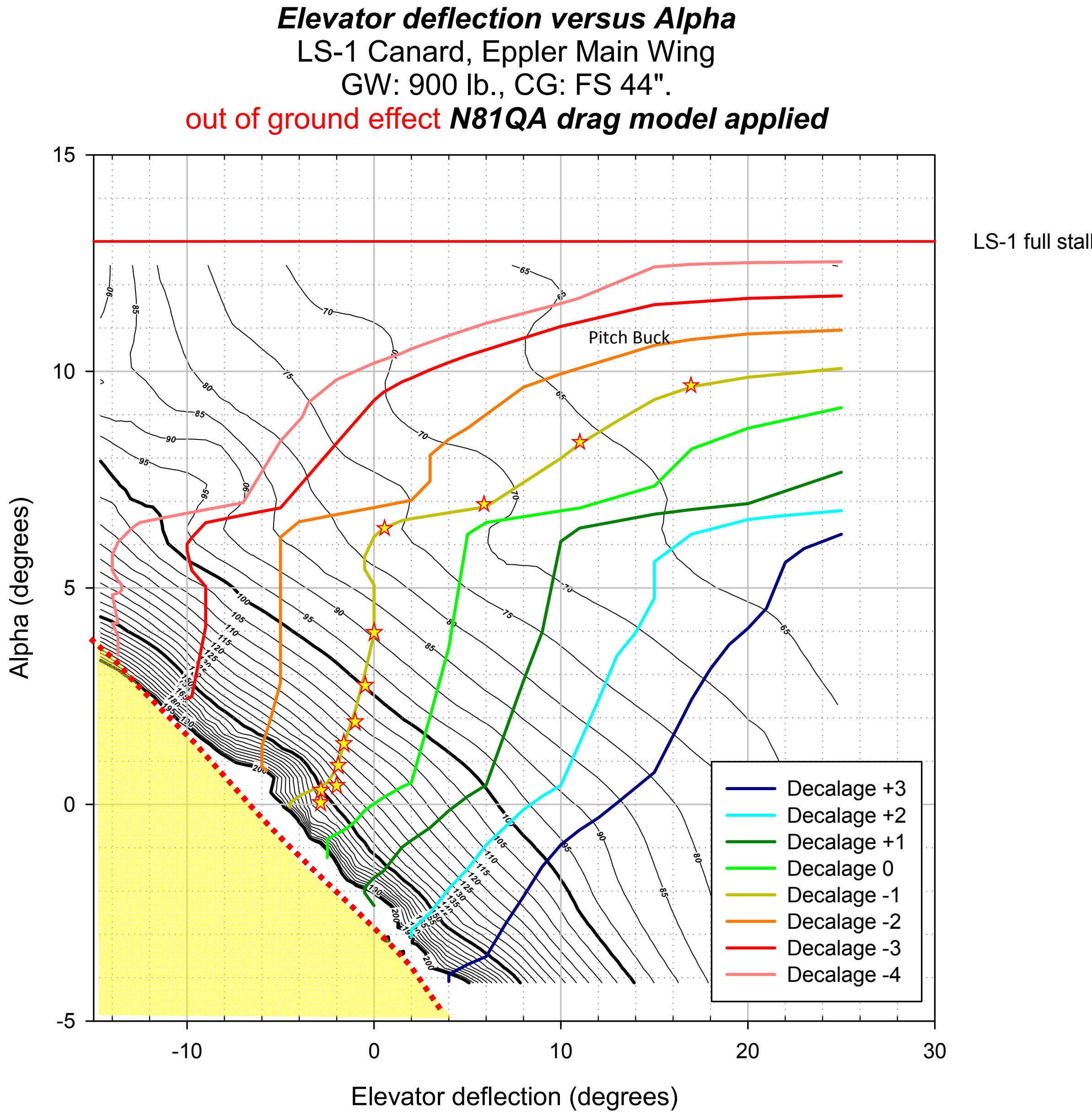


Figure 1. *Flight configuration curves for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44". Each colored curve represents allowable points for level flight for each decalage value. The results are for flight out of ground effect. The yellow stars represent actual flight test measurements from the QAC Q-200 prototype N81QA. The dotted curve represents the absolute Vne. Flight is likely to be unstable in yellow shaded region. See text for additional explanation.*

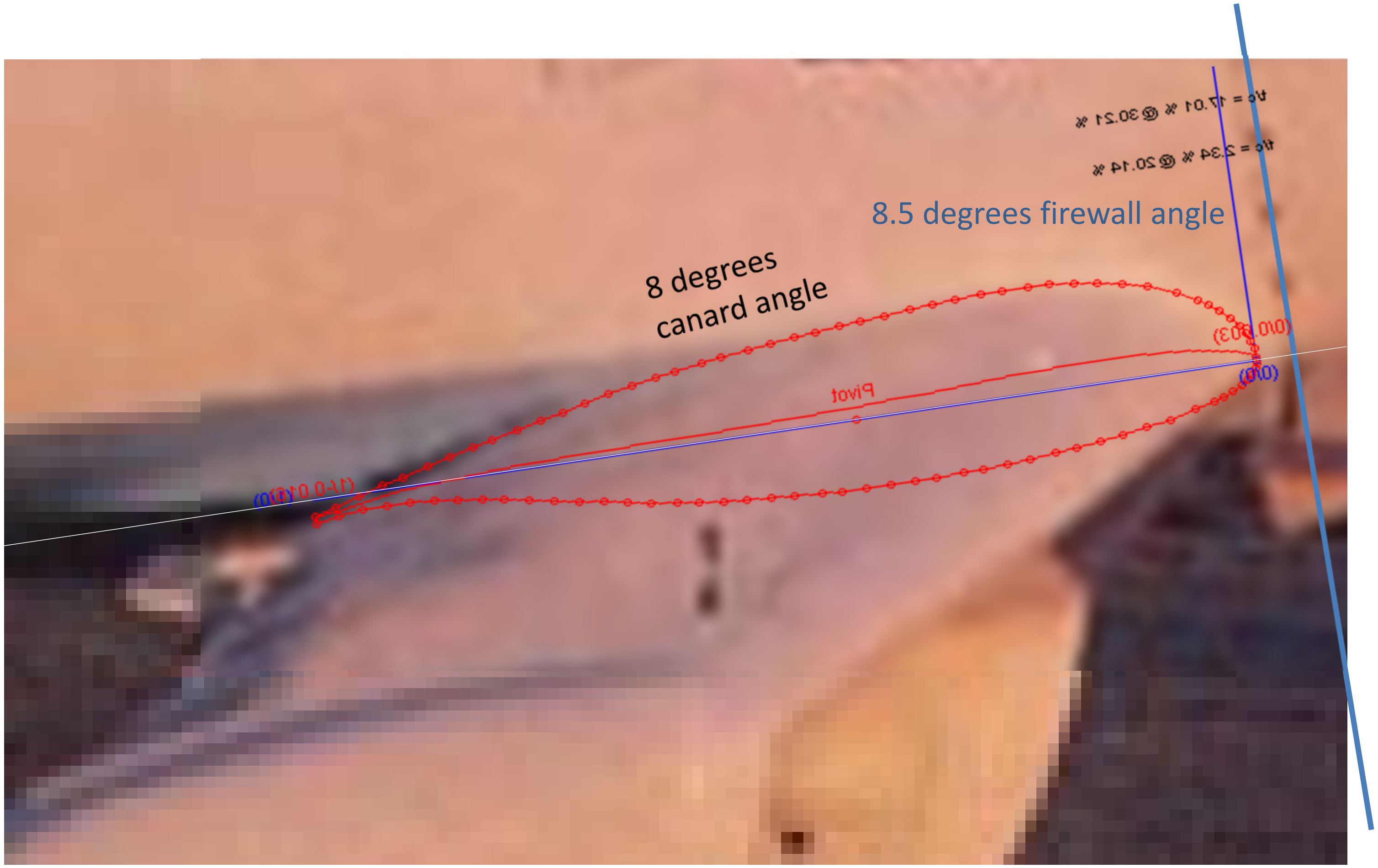


Figure 2. *Detail of historical photo of QAC Q-200 Prototype N81QA. The BL 15 QAC plans template for the LS-1 canard is matched to the photo in the proper location. This indicates that in this photo the Canard is at an 8 degree positive angle in this photo, and the firewall is slightly higher at about 8.5 degrees.*

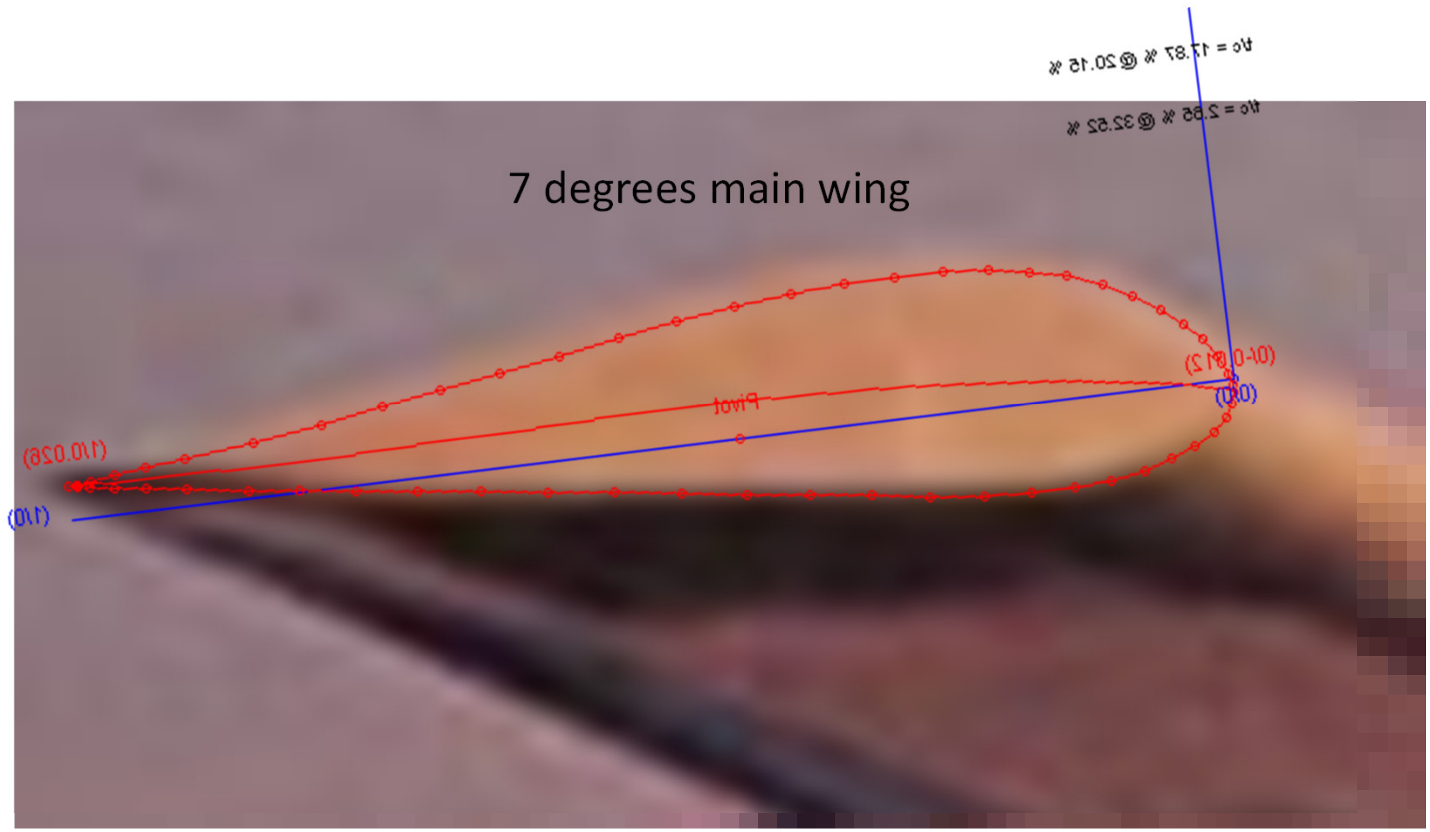


***Figure 3**. Detail of the same historical photo of QAC Q-200 shown in Figure 1. The BL 100 QAC plans template for the Eppler 1212 wing is matched to the photo in the proper location. This indicates that in this photo the Wing is at an 7 degree positive angle in this photo. Since the main wing is at 7 degrees and the canard is at 8 degrees. This photo, as well as other photos confirm that N81QA has a decalage of minus 1.*

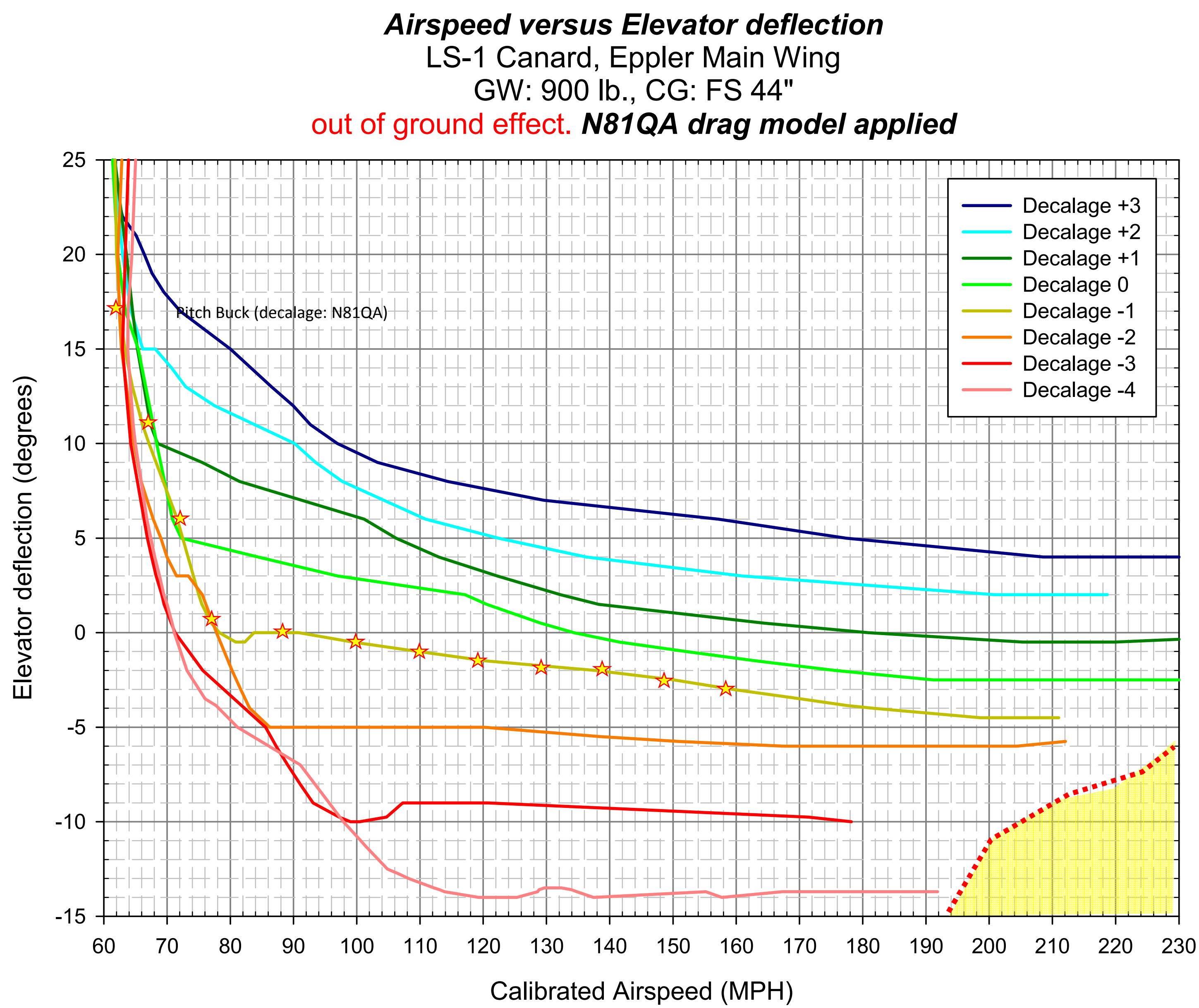


Figure 4. *Flight configuration curves for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44"*
Each colored curve represents allowable points for level flight for each decalage value. The results are for flight out of ground effect. The yellow stars represent actual flight test measurements from the QAC Q-200 prototype N81QA. The dotted curve represents the absolute Vne. Stable flight not possible in yellow shaded region.

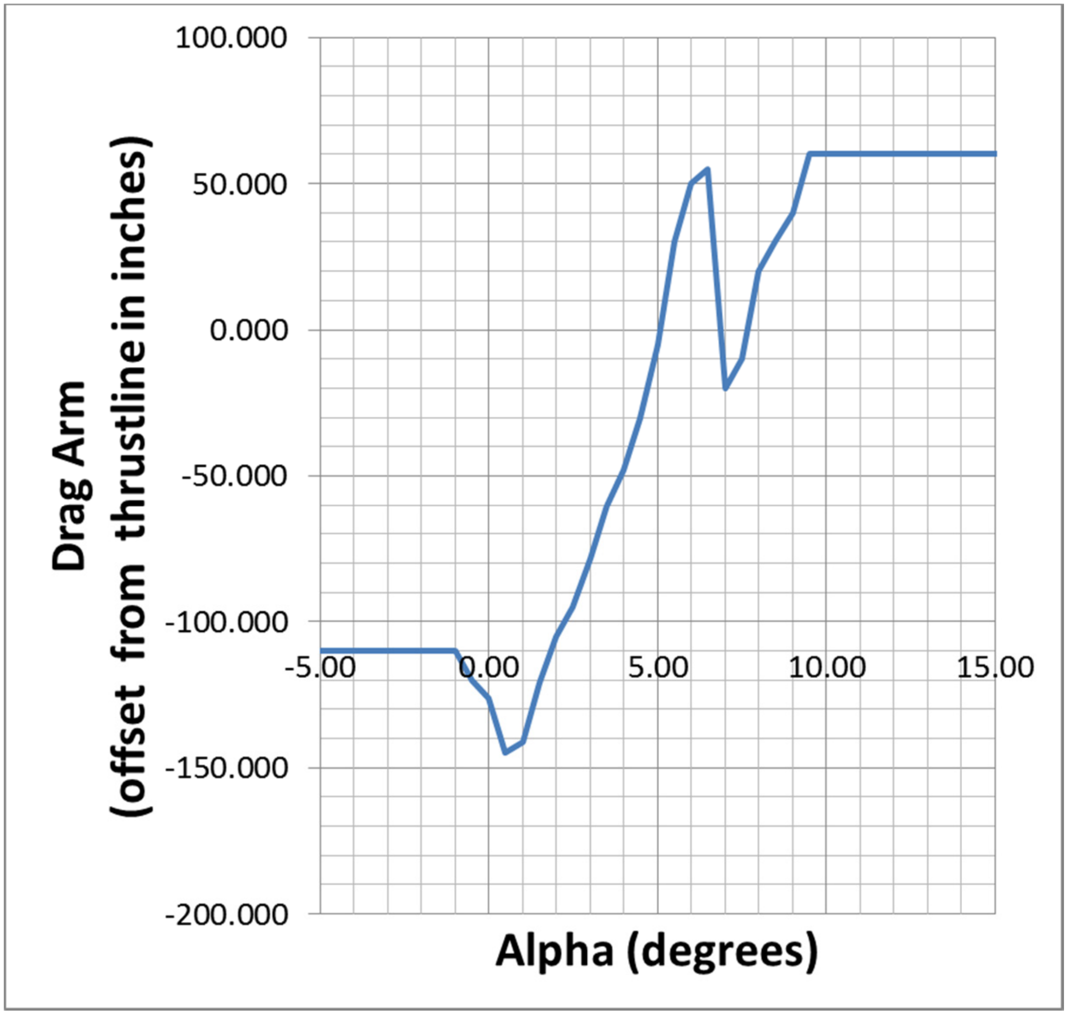


Figure 5. *Lift-independent non-wing drag moment-arm vs. Alpha model applied to Javafoil model. This variable arm model is required to cause the elevator deflections and airspeeds in the model to match the actual N81QA flight test data. Negative values of drag arm mean that the arm is below the thrust line, resulting in a forward pitching moment. The drag force applied to this arm is computed from the standard drag formula so is proportional to the square of airspeed.*

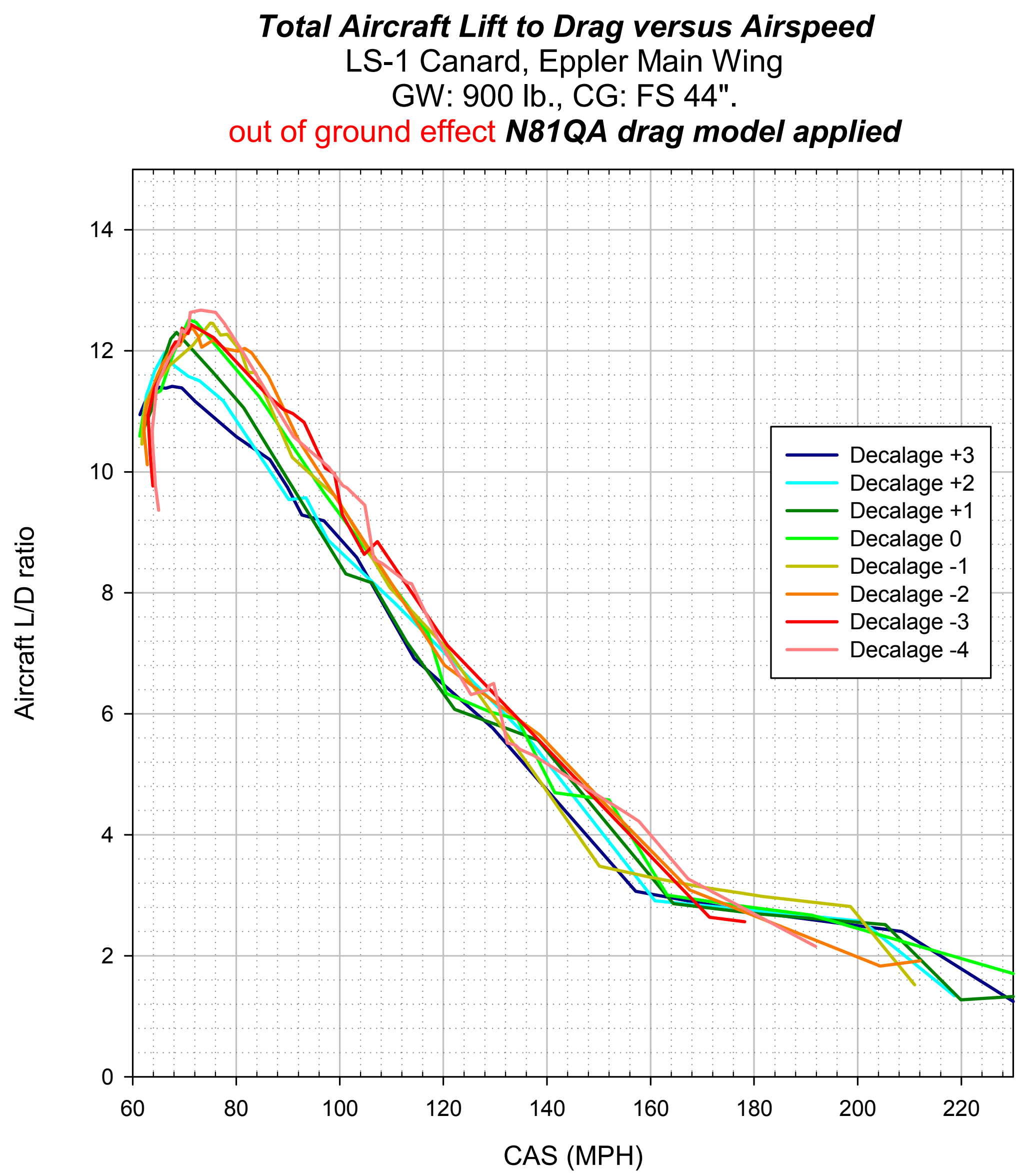


Figure 6. *Total Aircraft Lift to Drag (L/D) vs Airspeed (CAS) for the N81QA Q-200 model. The range of decalages modeled is -4 to +3. All decalage models show max L/D below 80 mph CAS, with decalage of -2 and -1 very below 70 MPH. The decalage of +3 has a minimum glide angle near 65 mph. Decalage of 0 (plans built) achieves the highest L/D, of 12.5at 72 mph CAS.`*

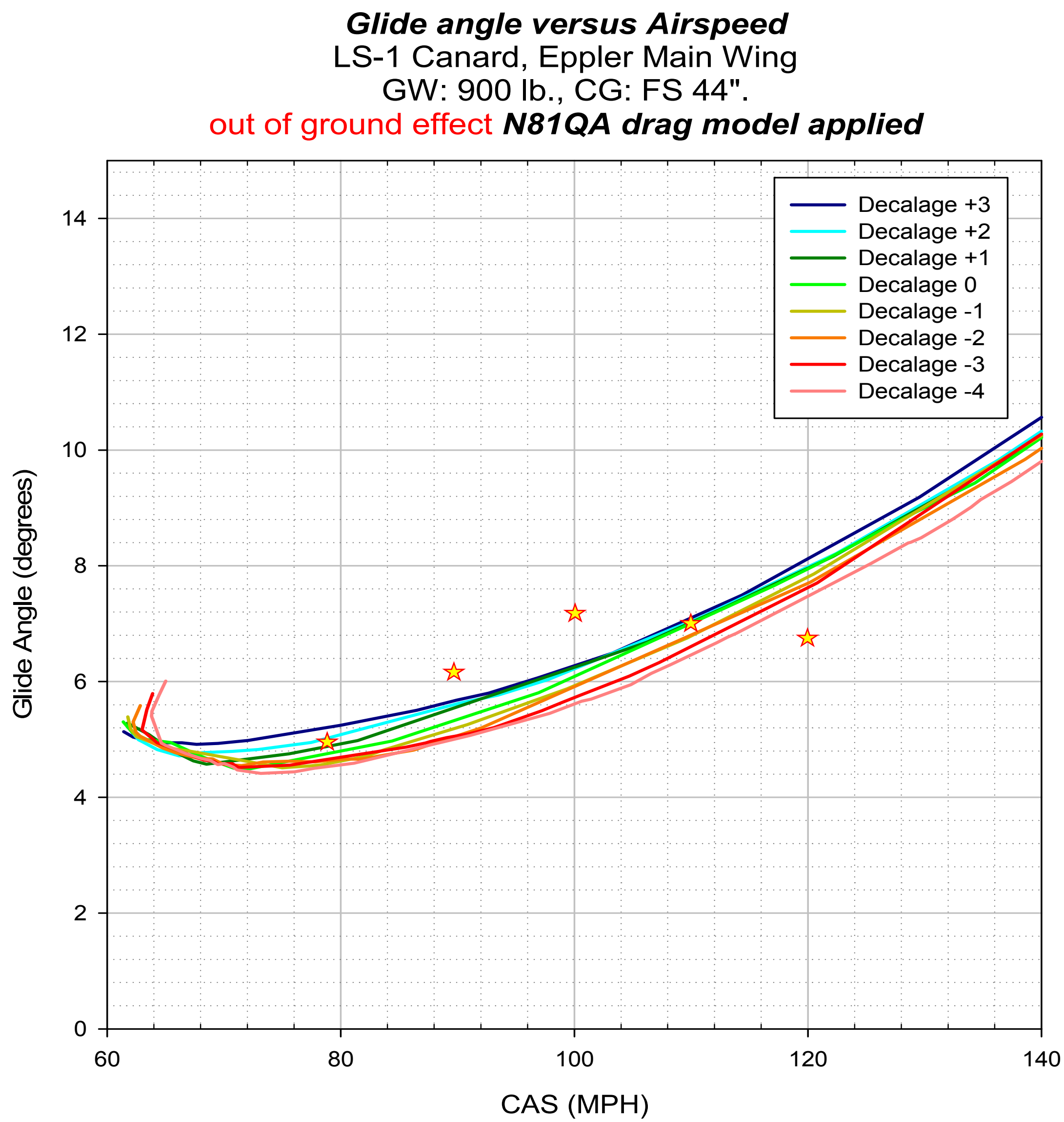
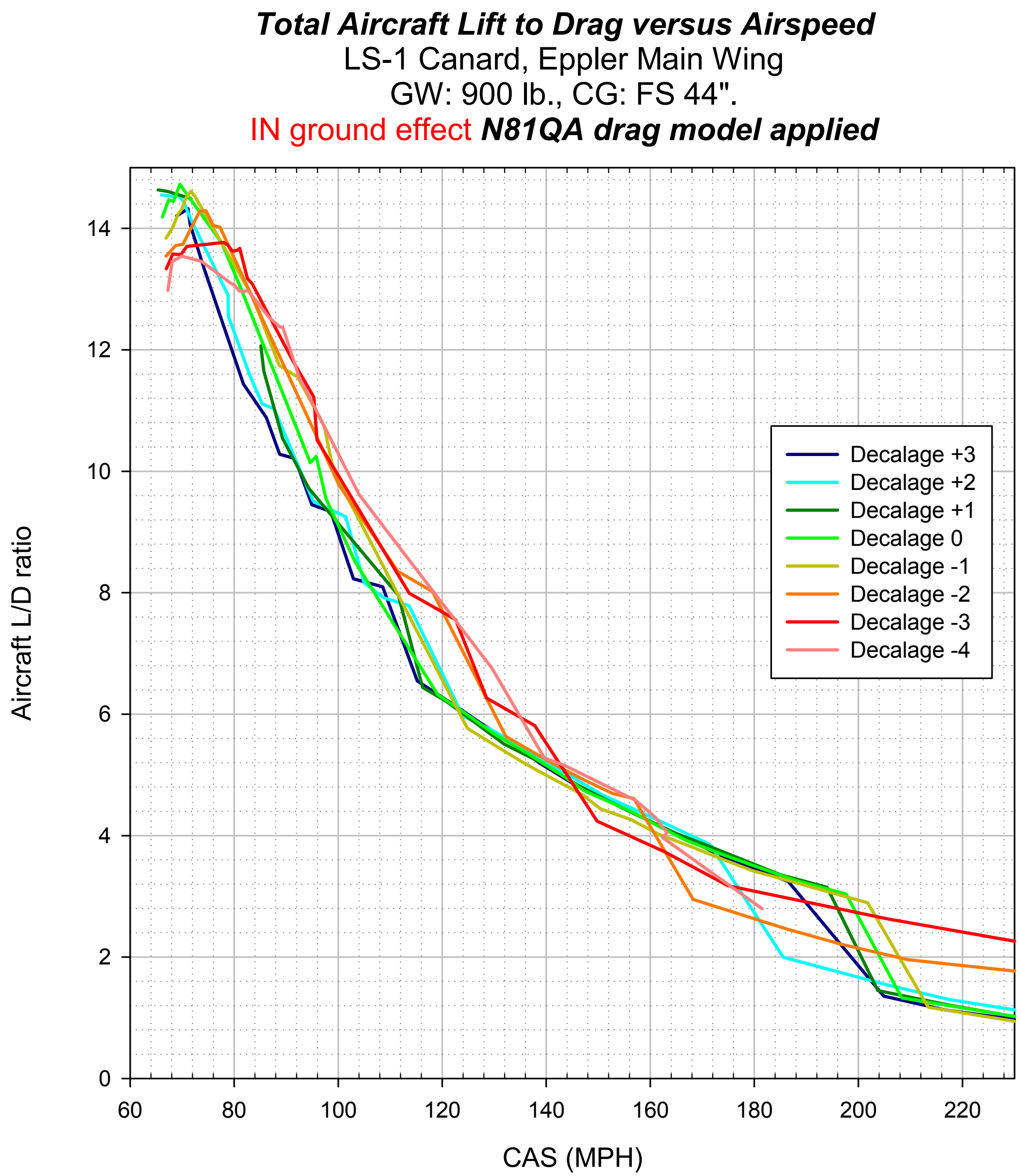


Figure 7. *Total Aircraft Glide Angle (degrees) vs Airspeed (CAS) for the N81QA Q-200 model. The range of decalage values is -4 to +3. All decalage models show minimum glide angle is achieved at airspeeds below 80 mph CAS, with decalage of -2 and -1 very below 70 MPH. The decalage of +3 (dark blue) has a minimum glide angle near 65 mph. Decalage of 0 (plans built) achieves the minimum glide angle near 4.5 degrees at 72 mph CAS. This corresponds to a glide ratio of near 12.5:1. The yellow stars represent glide angles vs. CAS measured on the QAC prototype Q-200, N81QA.*



Total Aircraft Lift to Drag (L/D) vs Airspeed (CAS) for the N81QA Q-200 model. The range of decalage modeled is -4 to +3. These curves represent response in ground effect.

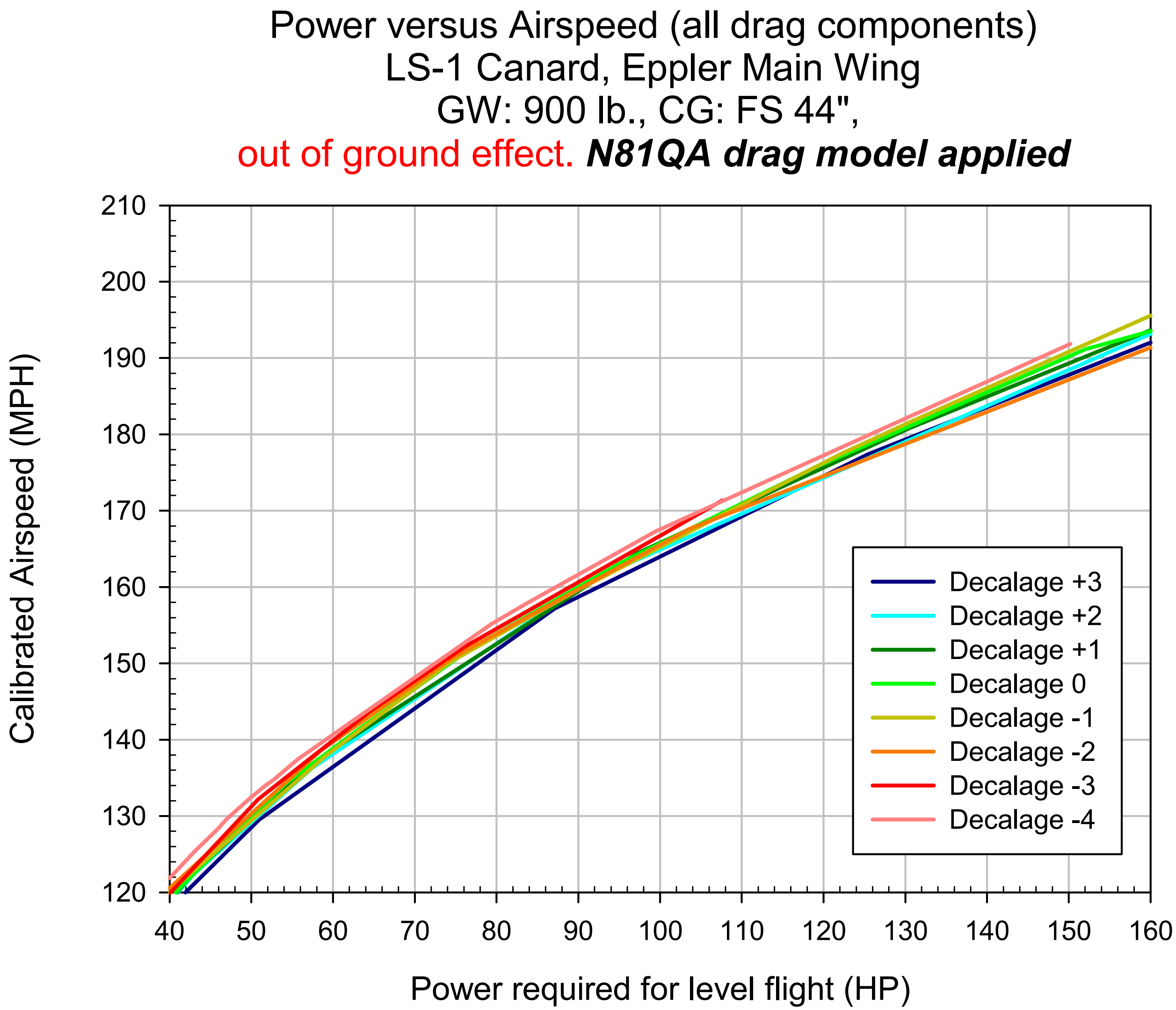


Figure 8. *Airspeed (CAS) as a function of power (HP) in level flight for the Q-2, LS1 Canard and the N81QA drag model applied. Note that high decalage values of +3 and +2 are the least efficient in the 120-180 CAS range, which decalage values of -3 and -4 decalage are the most efficient. The range is about 6 MPH at 100 HP.*

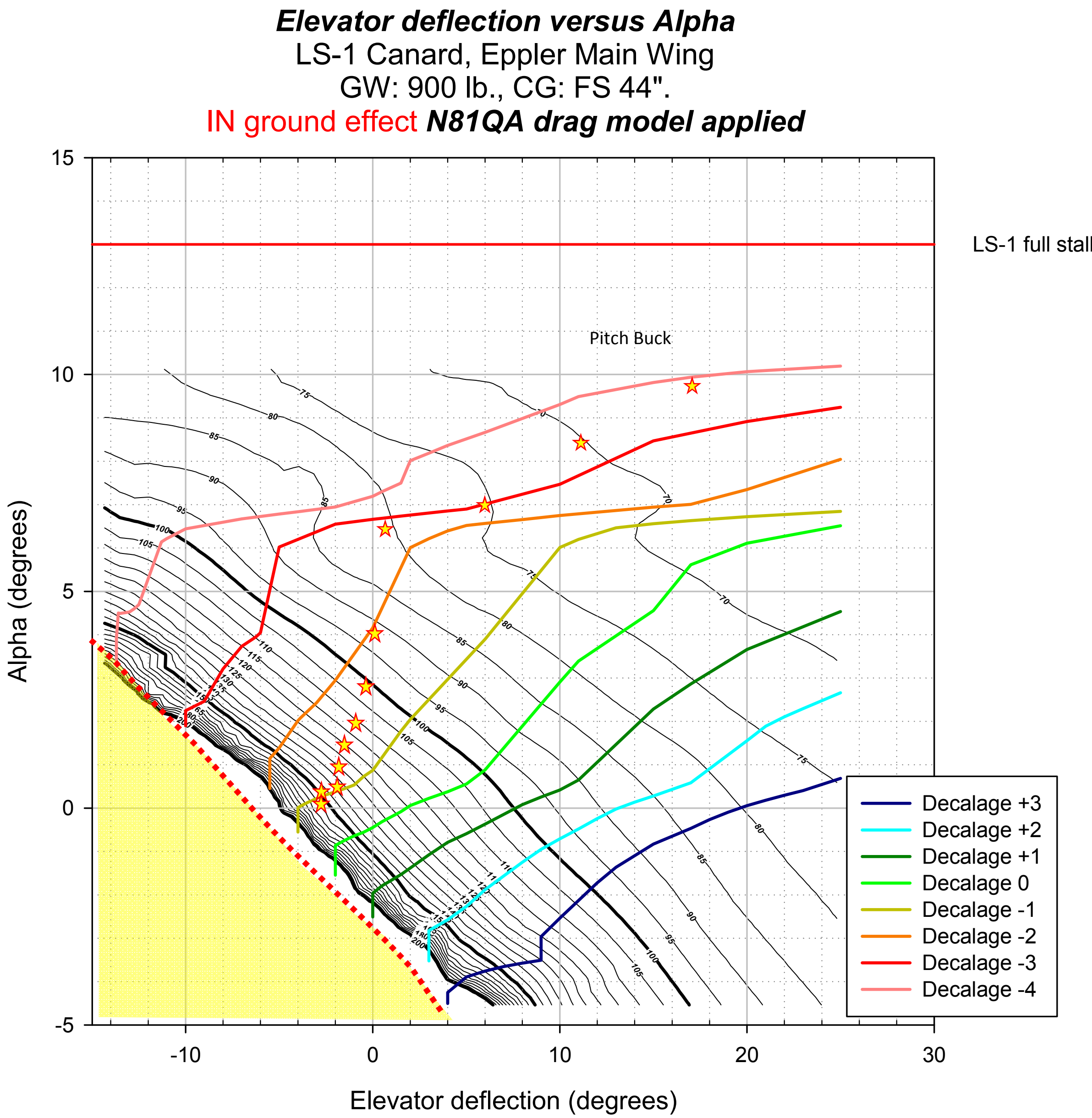


Figure 9. *Flight configuration curves for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44" in ground effect. Each colored curve represents allowable points for level flight for each decalage value. The yellow stars represent flight test measurements from the QAC Q-200 prototype N81QA outside of ground effect (same as shown on Figure 1) . Note the significant difference to Figure 1.*

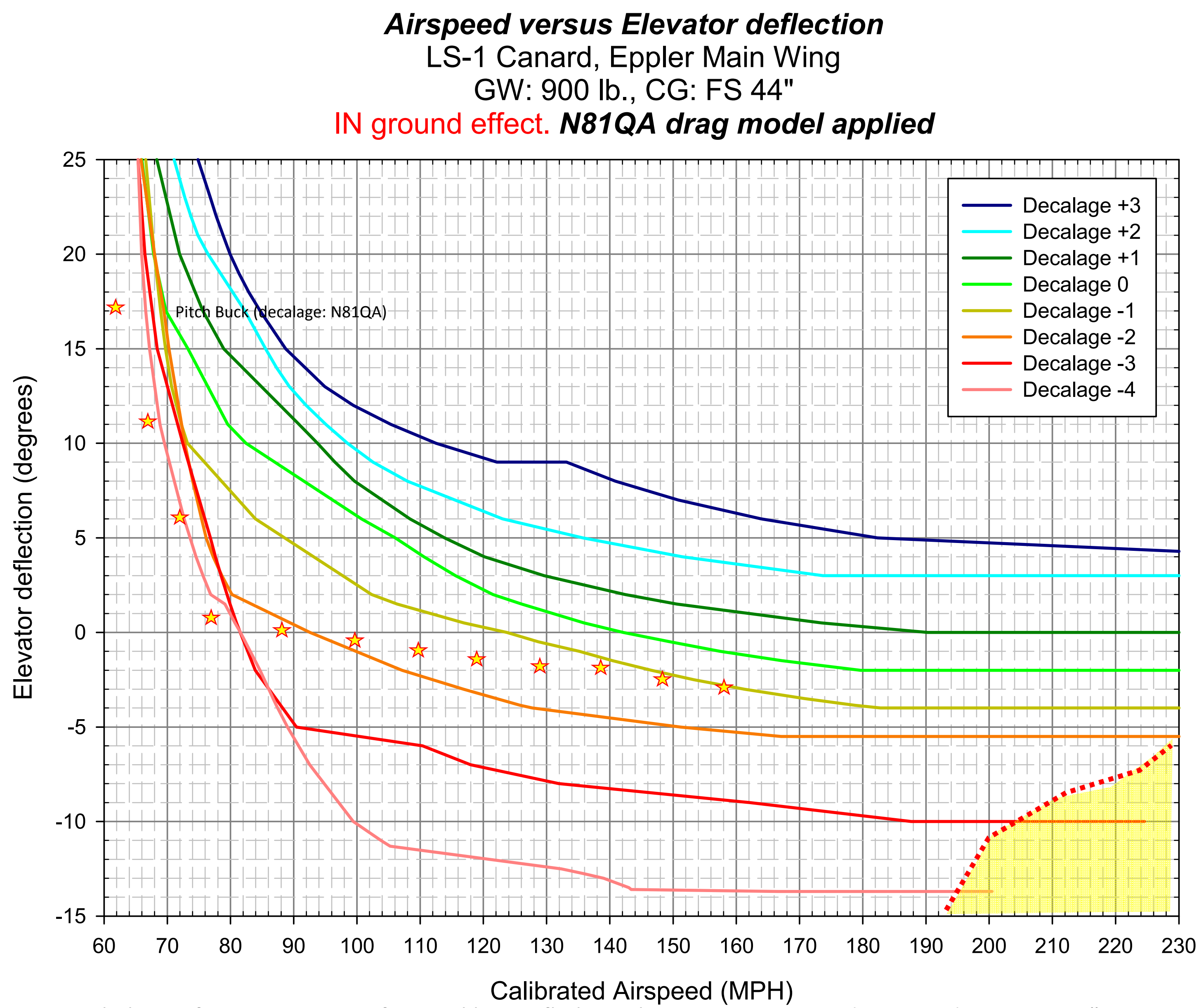


Figure 10. *Flight configuration curves for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44" in ground effect. Each colored curve represents allowable points for level flight for each decalage value. The yellow stars represent actual flight test measurements from the QAC Q-200 prototype N81QA out of ground effect. Note the difference between modeled flight in ground effect and the stars which were measured outside of ground effect.*

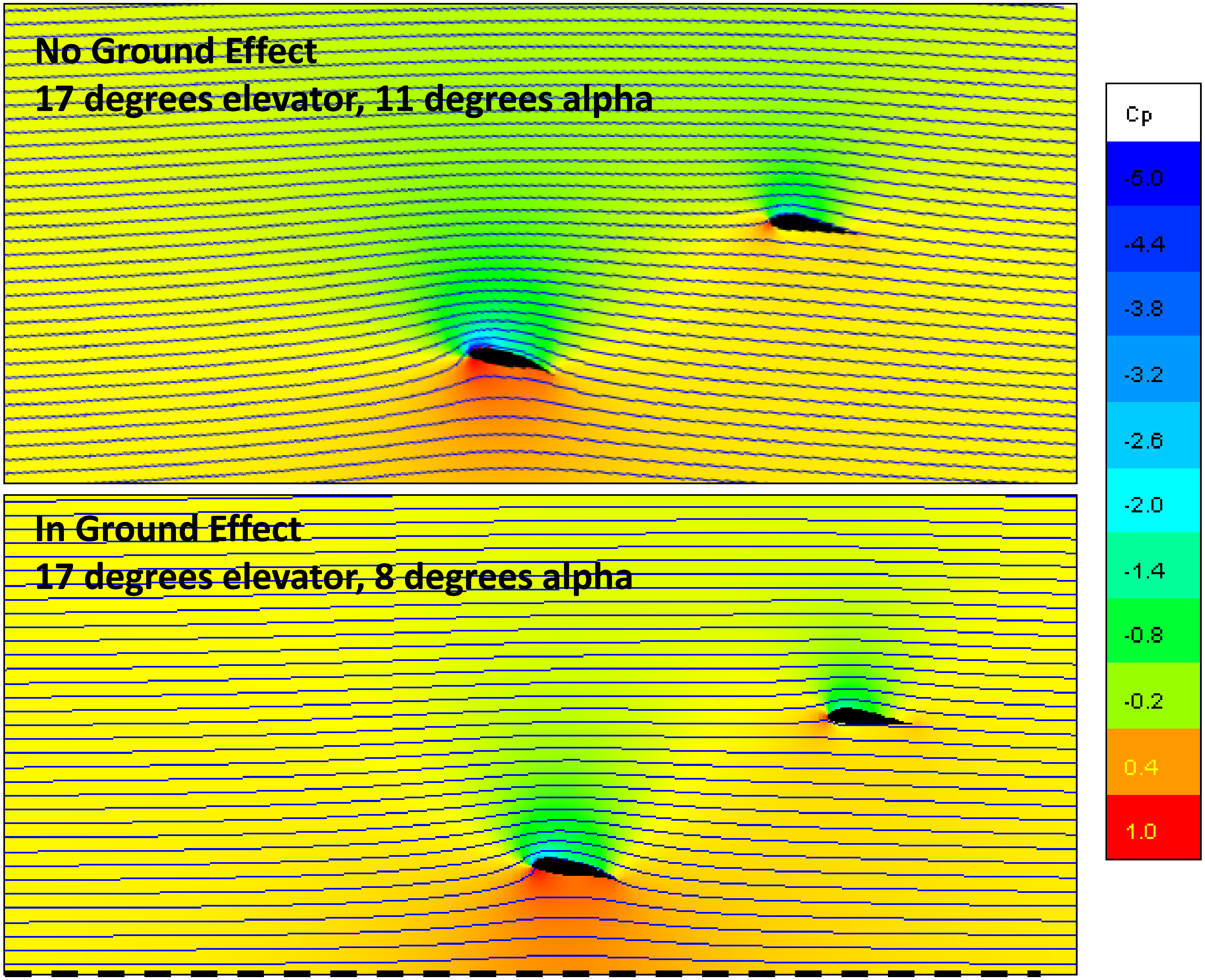


Figure 11. *Vertical pressure distribution maps for level flight in the Q-2 at 900 pounds GW and CG @ FS 44" both in and out of ground effect. The upper map shows coefficient of pressure (Cp) for flight out of ground effect and the lower maps shows Cp in ground effect. Yellow represents Cp of 0 (ambient atmospheric pressure). Greens and blues indicate reduced pressure. Oranges and reds indicate elevated pressure. Dark blue lines are streamlines. Note that despite identical elevator deflection (17 deg.), flight in ground effect reduces alpha from 11 to 8 degrees.*

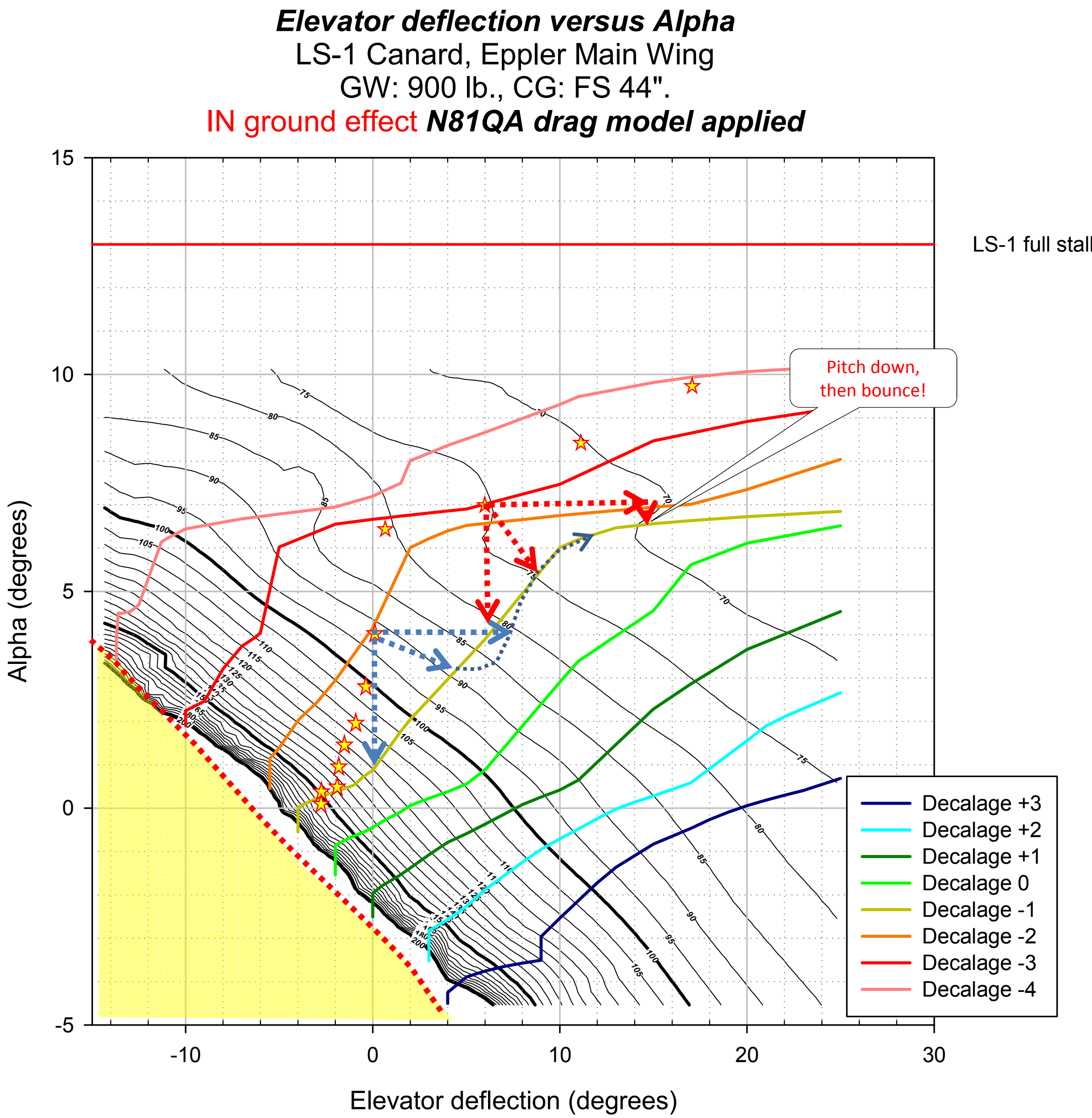


Figure 12. *Flight configuration curves for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44" in ground effect. Each colored curve represents allowable points for level flight for each decalage value. The yellow stars represent flight test measurements from the QAC Q-200 prototype N81QA out of ground effect. The significance of the blue and red dashed arrow is discussed in detail in the text.*

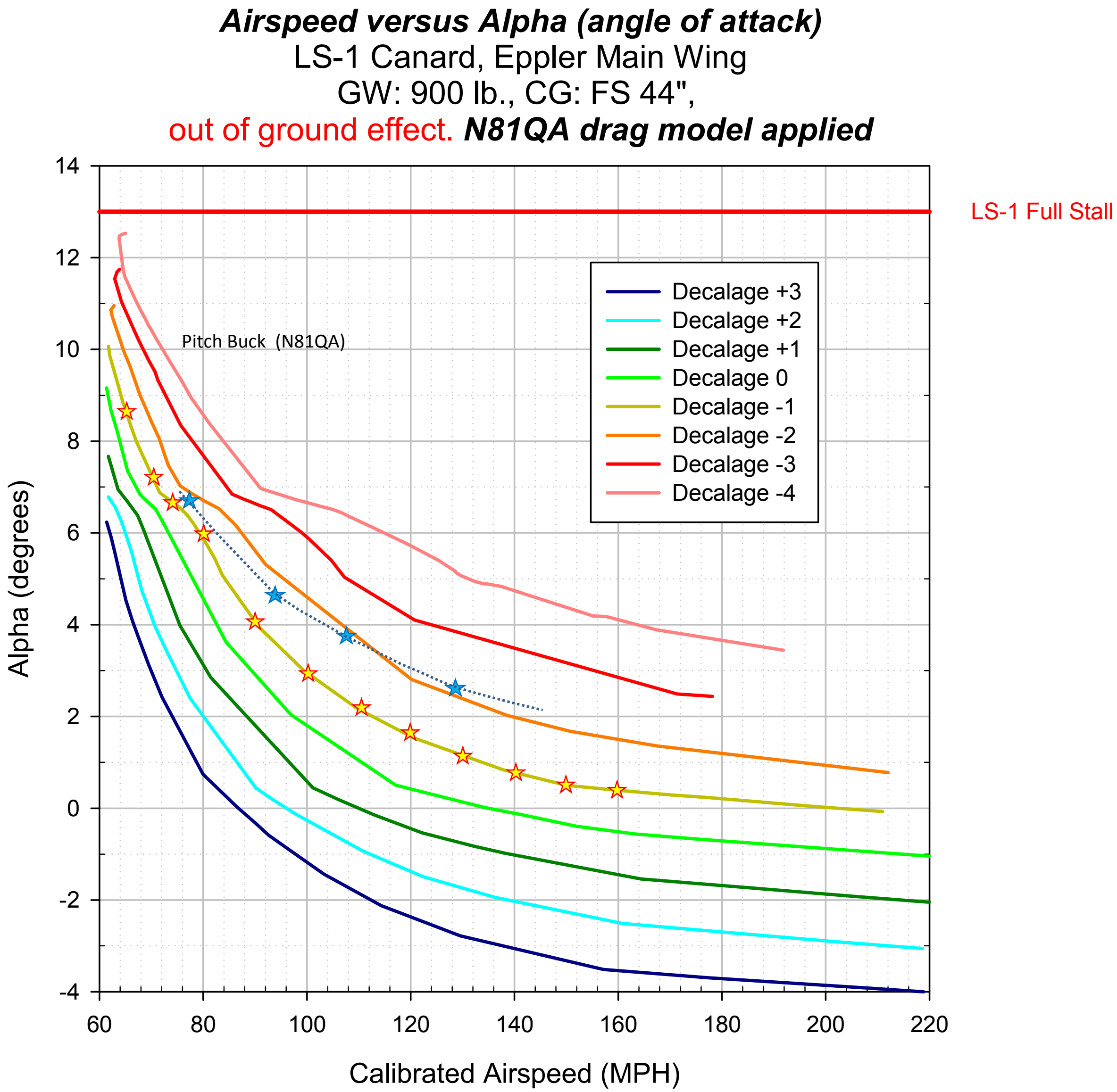


Figure 13. *Airspeed versus alpha data. The blue stars represent the estimated flight test data points from video analysis of a similarly loaded Tri-Q 200 with a decalage of minus 0.4 degrees. The colored curves are for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44". The results are for flight out of ground effect. The yellow stars represent actual flight test measurements from the QAC Q-200 prototype N81QA. Note the differences between the blue stars (Tri-Q200) and the yellow stars (Q-200), with similar decalage configurations.*

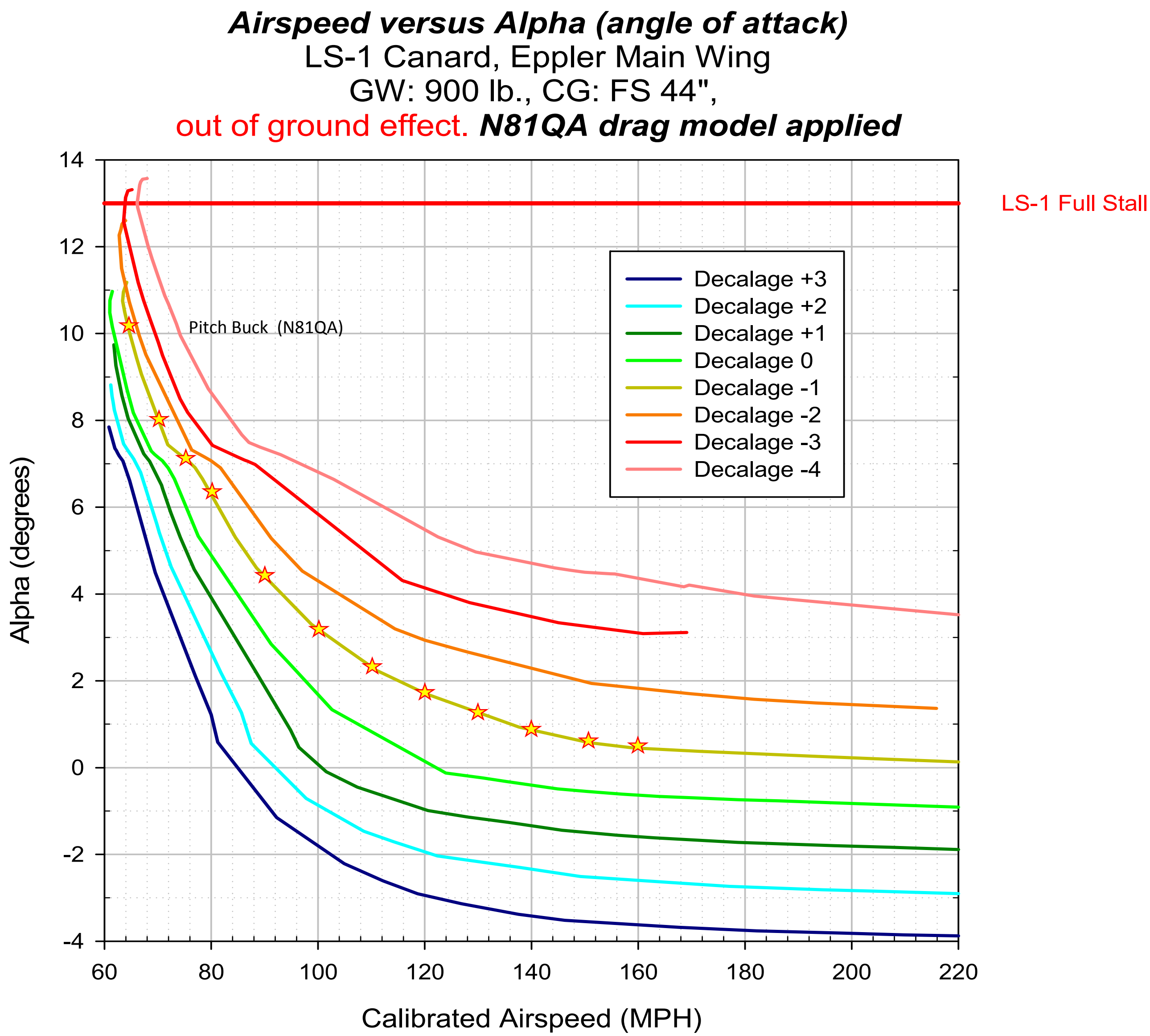


Figure 12. *Airspeed versus alpha curves for equilibrium flight in the Q-2 at 900 pounds GW and CG @ FS 44"*
Each colored curve represents allowable points for level flight for each decalage value. The results are for flight out of ground effect. The yellow stars represent actual flight test measurements from the QAC Q-200 prototype N81QA. The blue stars represent the estimated flight test data points from video analysis of a similarly loaded Tri-Q 200 with a decalage of minus 0.4 degrees.

Airflow streamlines over Tri-Q (zero decalage) at Alpha=0

Out of ground effect

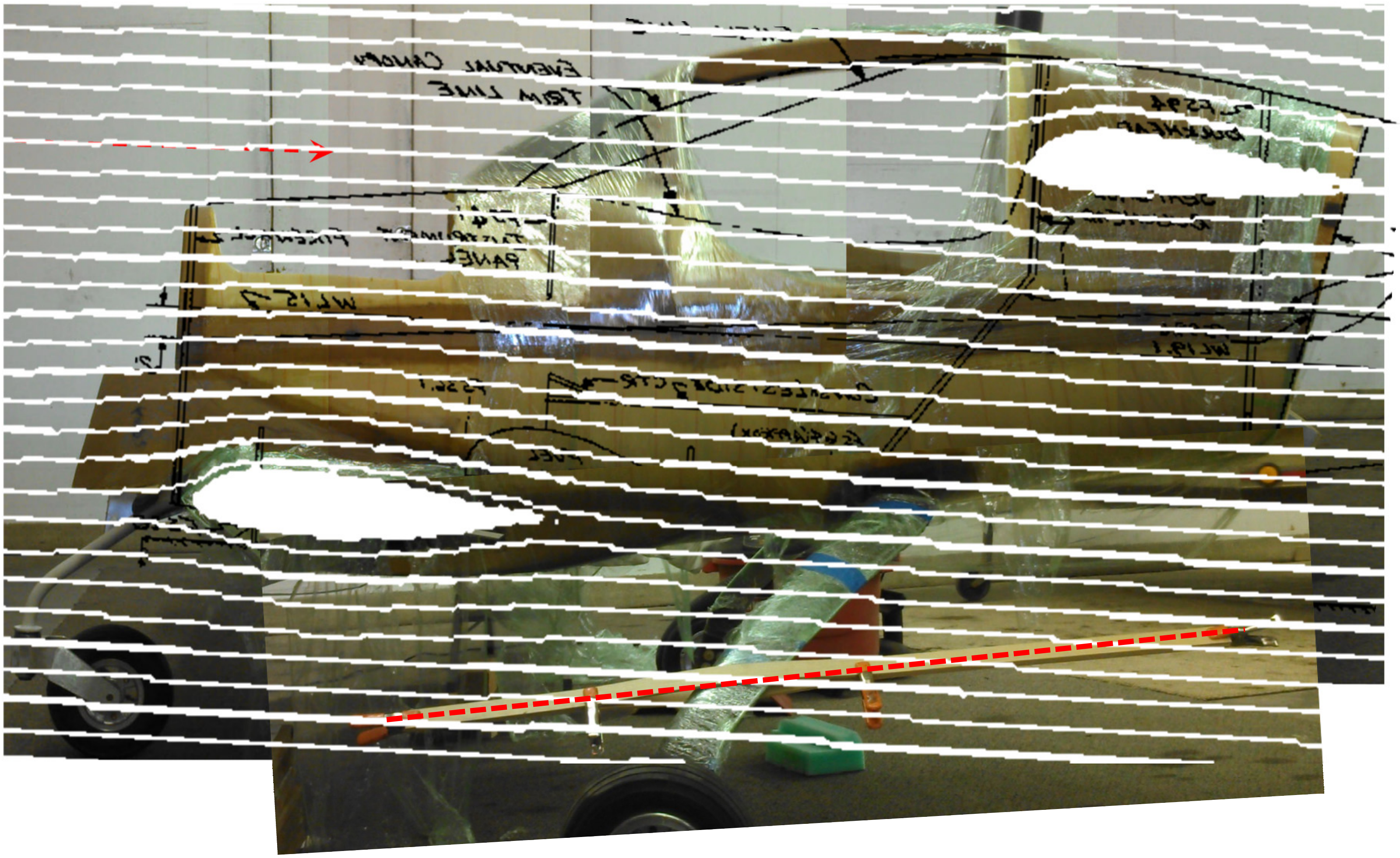


Figure 14. *Measurement of mean chord of the outer part the main gear leg's mean chord angle (red dashed curve) versus Javafoil streamlines (white) laid over partially built Tri-Q2. The red line makes a negative 15 degree angle to the relative wind when the aircraft is flying at Alpha=0 .*

Airflow streamlines over Tri-Q (zero decalage) at Alpha=0
Out of ground effect

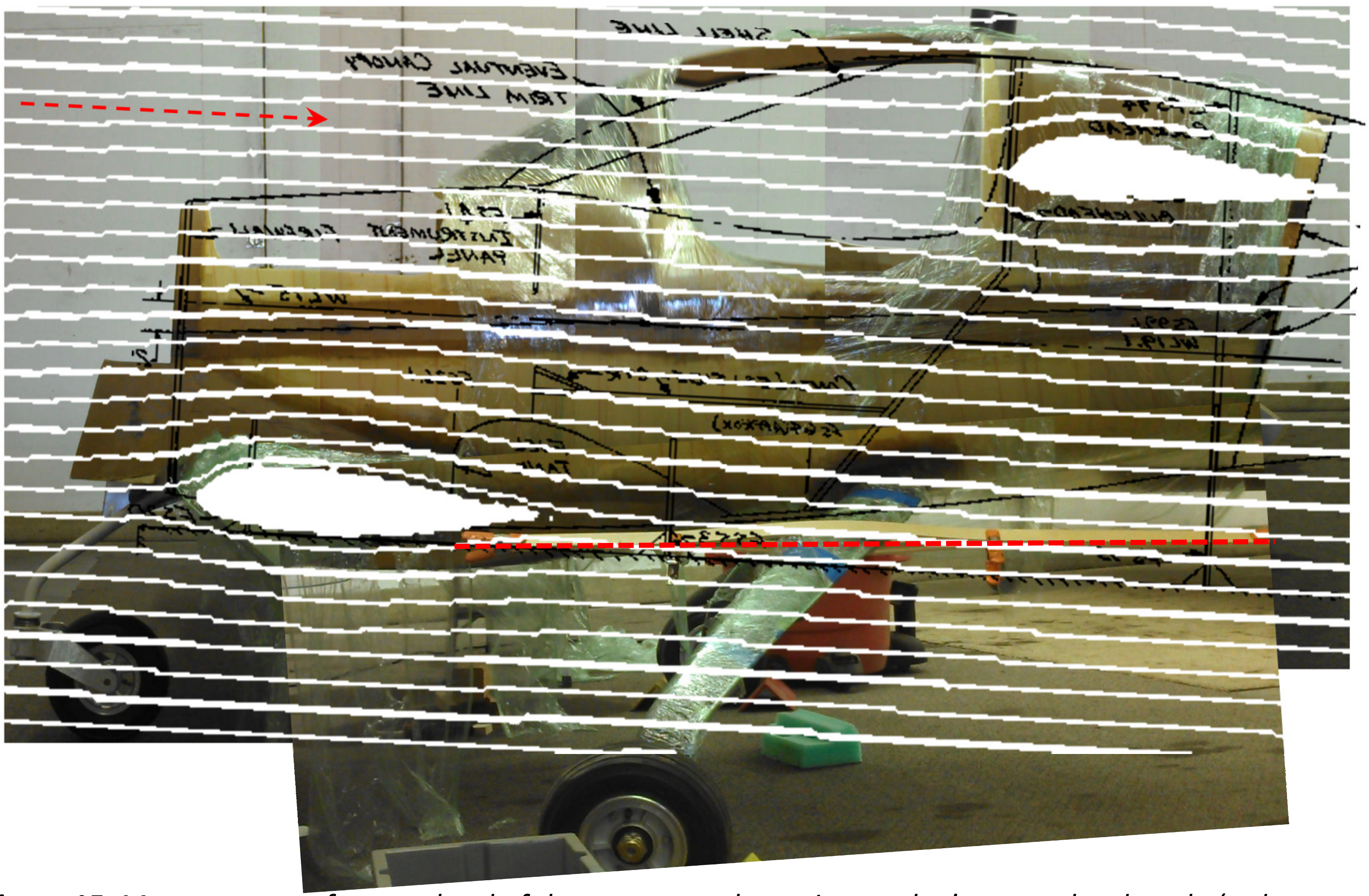


Figure 15. *Measurement of mean chord of the outer part the main gear leg's mean chord angle (red dashed curve) versus Javafoil streamlines (white) laid over partially built Tri-Q2. The red line makes a negative 8 degree angle to the relative wind when the aircraft is flying at Alpha=0 .*

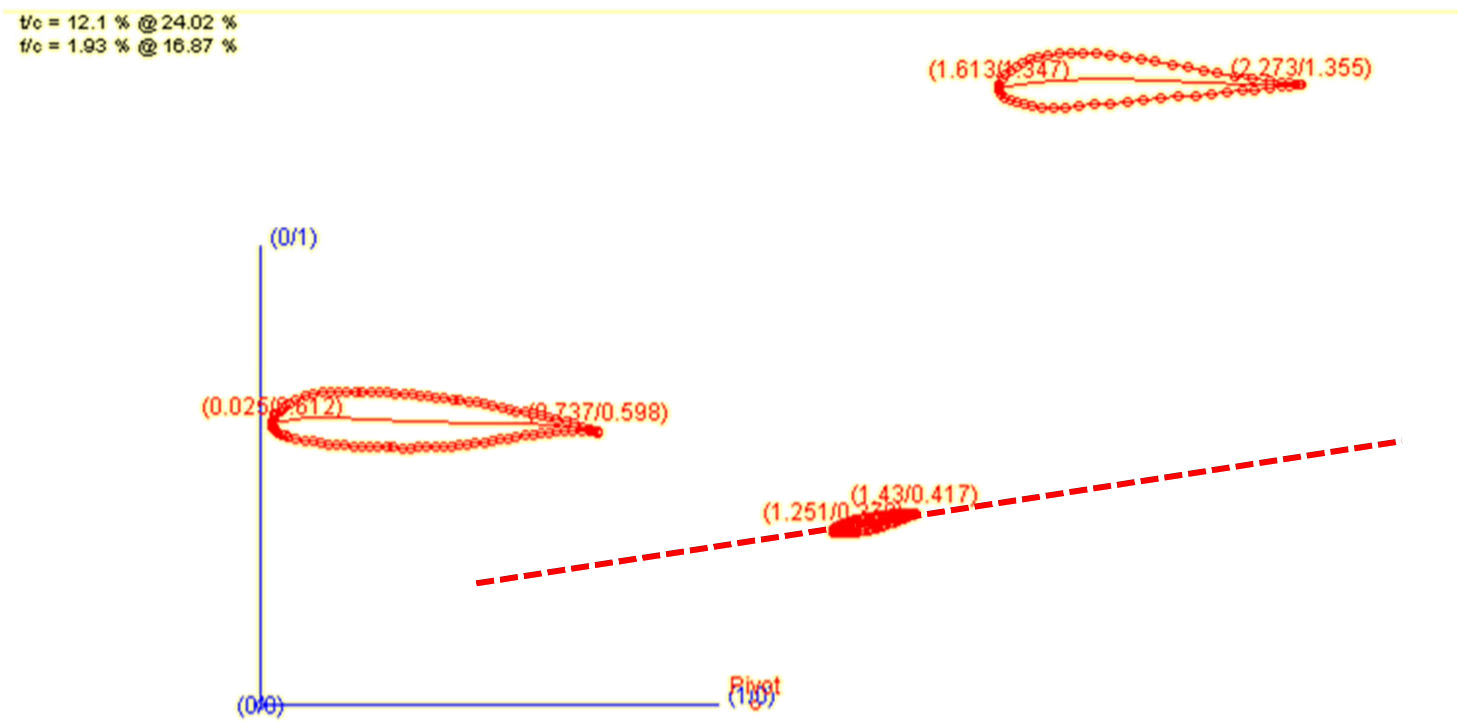


Figure 16. *JavaFoil model wing sections for inner "third" of Tri-Q200 layout. An additional small wing section representing the main landing gear has been added. The red "Pivot" label at the bottom is the contact point of the main gear with the runway for the Tri-Q200 configuration and is located at FS 56.5 when the aircraft is horizontal. The bottom blue line is the runway surface. The vertical blue line is the location of the firewall (FS 14). The section of the small landing gear foil has been rotated to represent the average incidence angle of the gear leg "wing" over its entire length from fuselage to main wheel.*

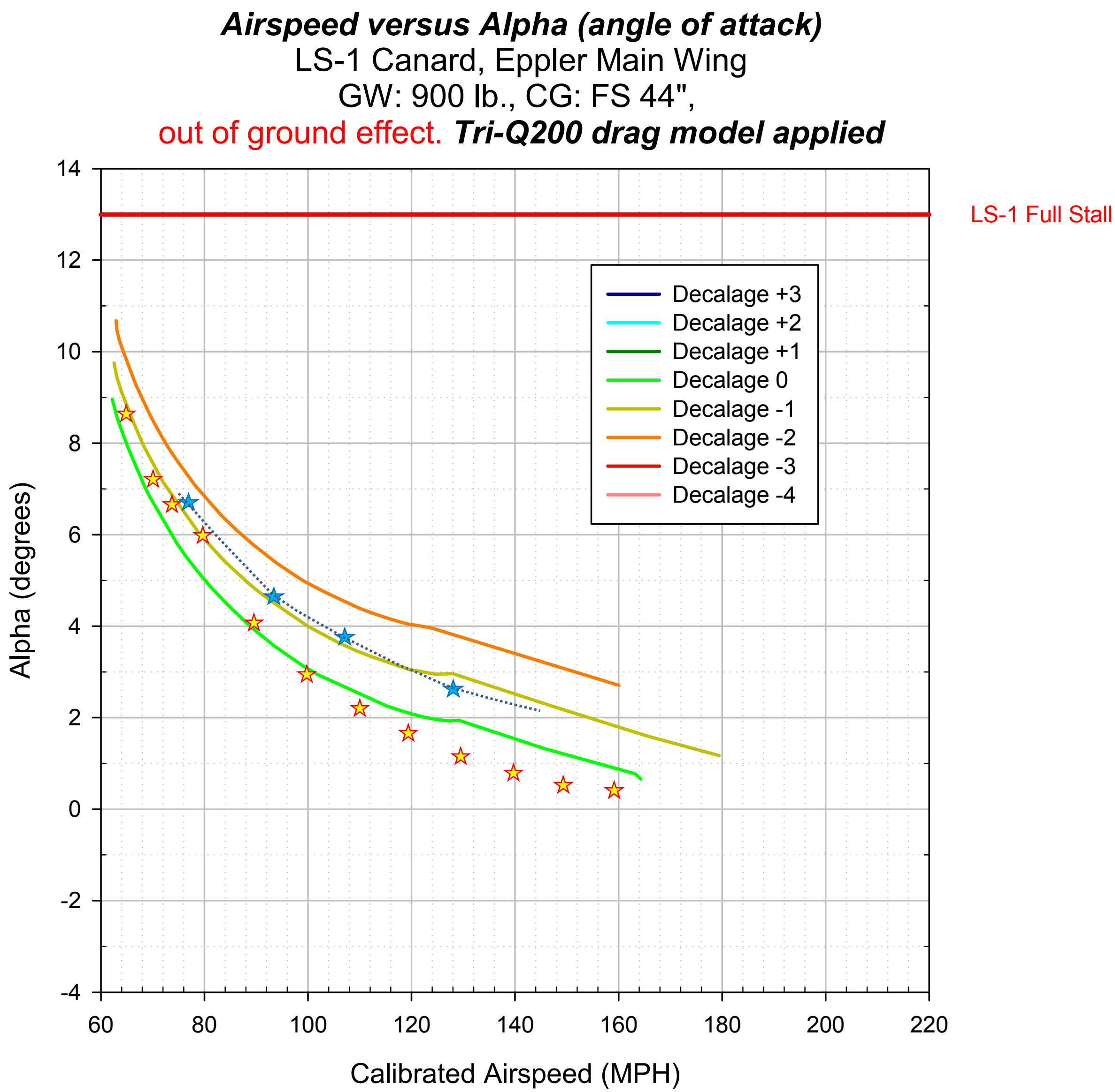


Figure 17. *Airspeed versus alpha data. The blue stars represent the estimated flight test data points from video analysis of a similarly loaded Tri-Q 200 with a decalage of minus 0.4 degrees. The colored curves are for equilibrium flight of the Tri-Q200 with the gear leg added as a third flying surface. The flight test is at 900 pounds GW and CG @ FS 44". The results are for flight out of ground effect. The yellow stars represent actual flight test measurements from the QAC Q-200 prototype N81QA. In this case, the blue stars lie on the decalage -1 curve or below it. The addition of the gear leg, made the match.*

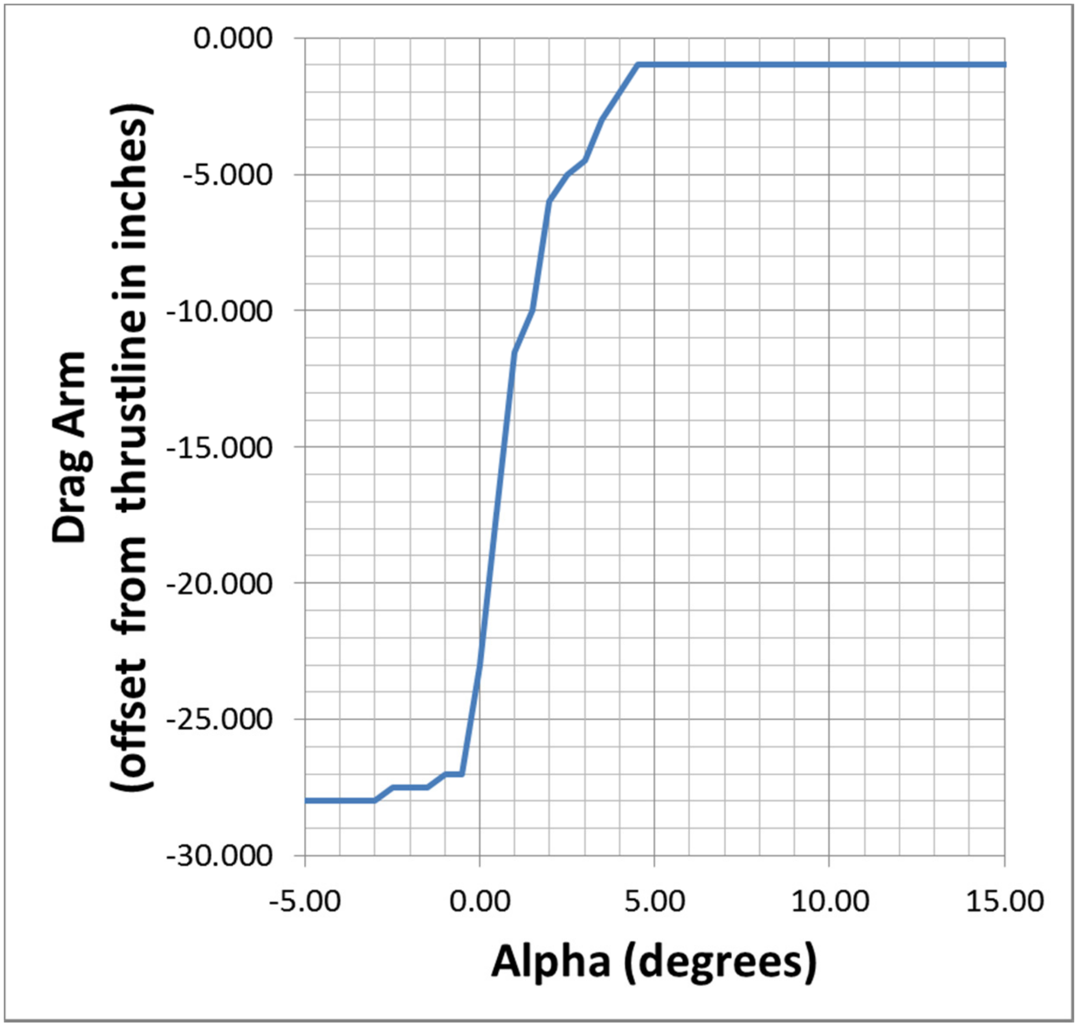


Figure 18. *Lift-independent non-lift drag moment-arm vs. Alpha model for the Tri-Q200 applied to Javafoil model. This model is typical of that expected for the Tri-Q200 where the gear leg drags are all located below the thrust . The drag force applied to this arm is computed from the drag formula so is proportional to the square of airspeed.*

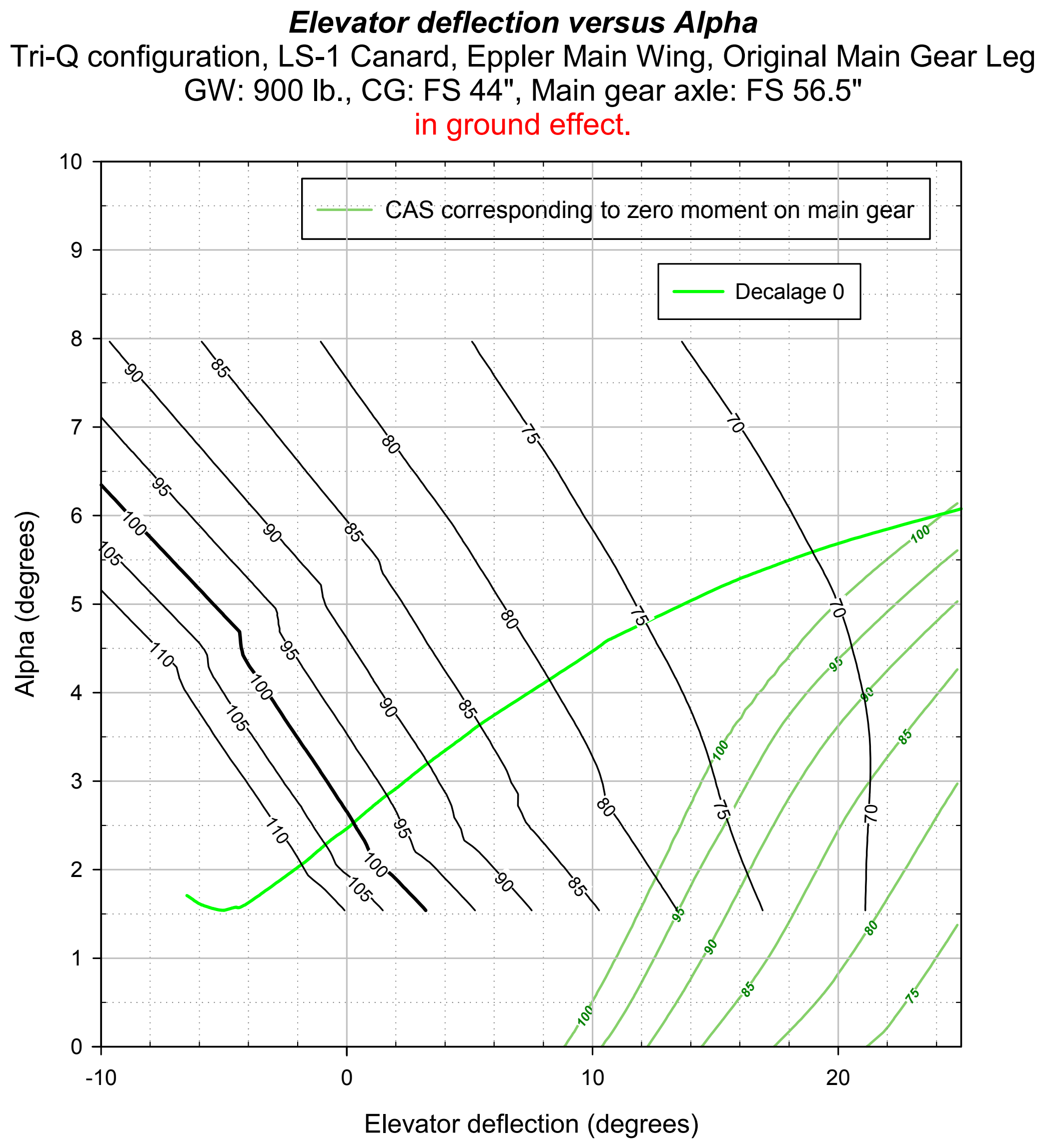


Figure 19. *Take off relationships for Tri-Q200 (decalage zero). The light green curve represents equilibrium flight configurations. The black contours represent CAS for each configuration. The dark green lines are labeled with CAS which will result in zero weight on the nose wheel (rotation condition). For example, if CAS is constant , increasing elevator deflection will cause the alpha to follow the green curve labeled with that CAS.*

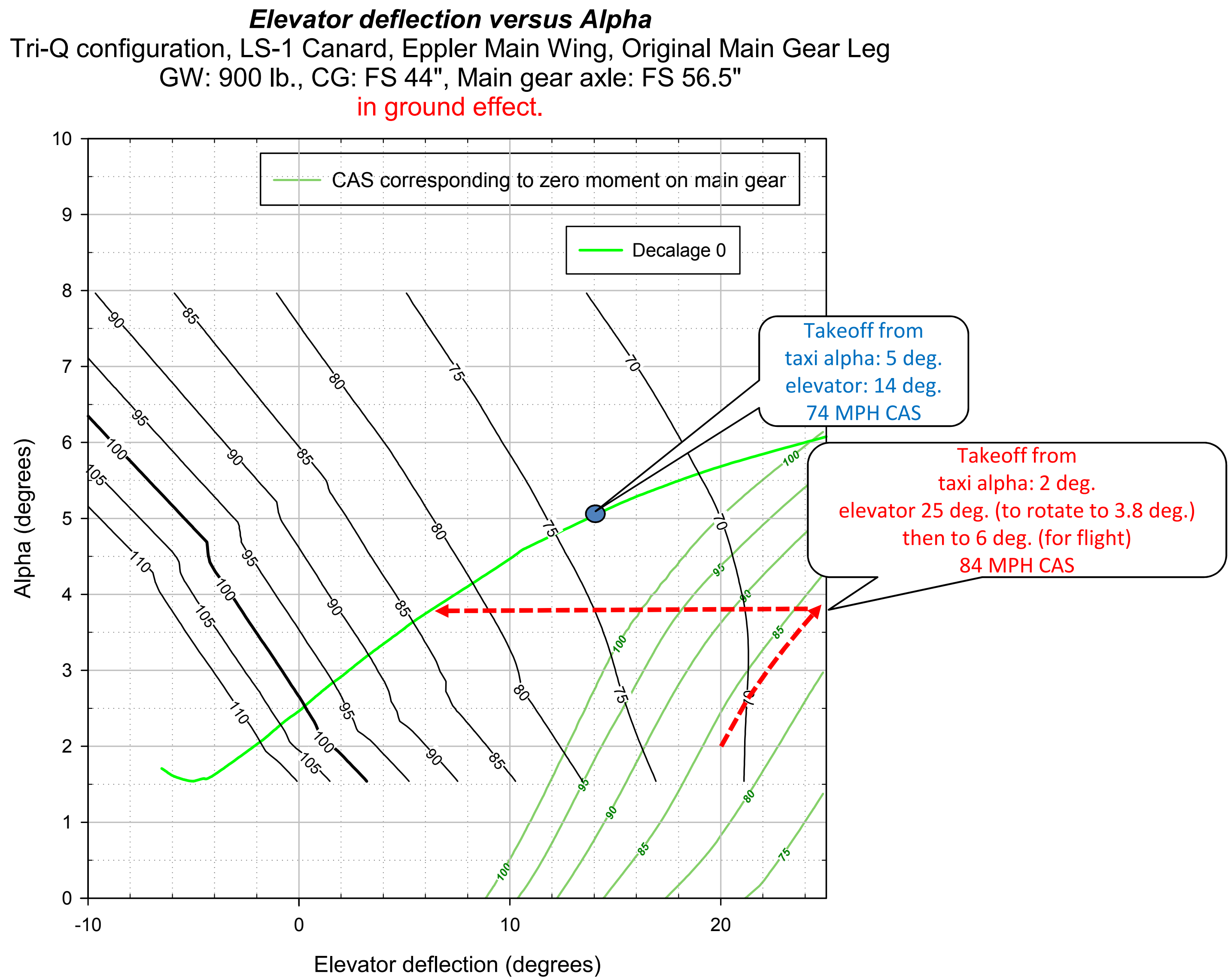


Figure 20. *Take off relationships for Tri-Q200 (decalage zero). Same as Figure 19. If the taxi ground angle is 5 degrees, the Tri-Q200 will take off at 74 MPH with elevator at 14 degrees (blue dot). The dashed red curve shows transition to take-off at for taxi alpha=2 degrees. 25 deg. elevator to rotate to 3.8 degrees at takeoff, then elevator is reduced to 6 degrees for flight (CAS of 83 MPH).*

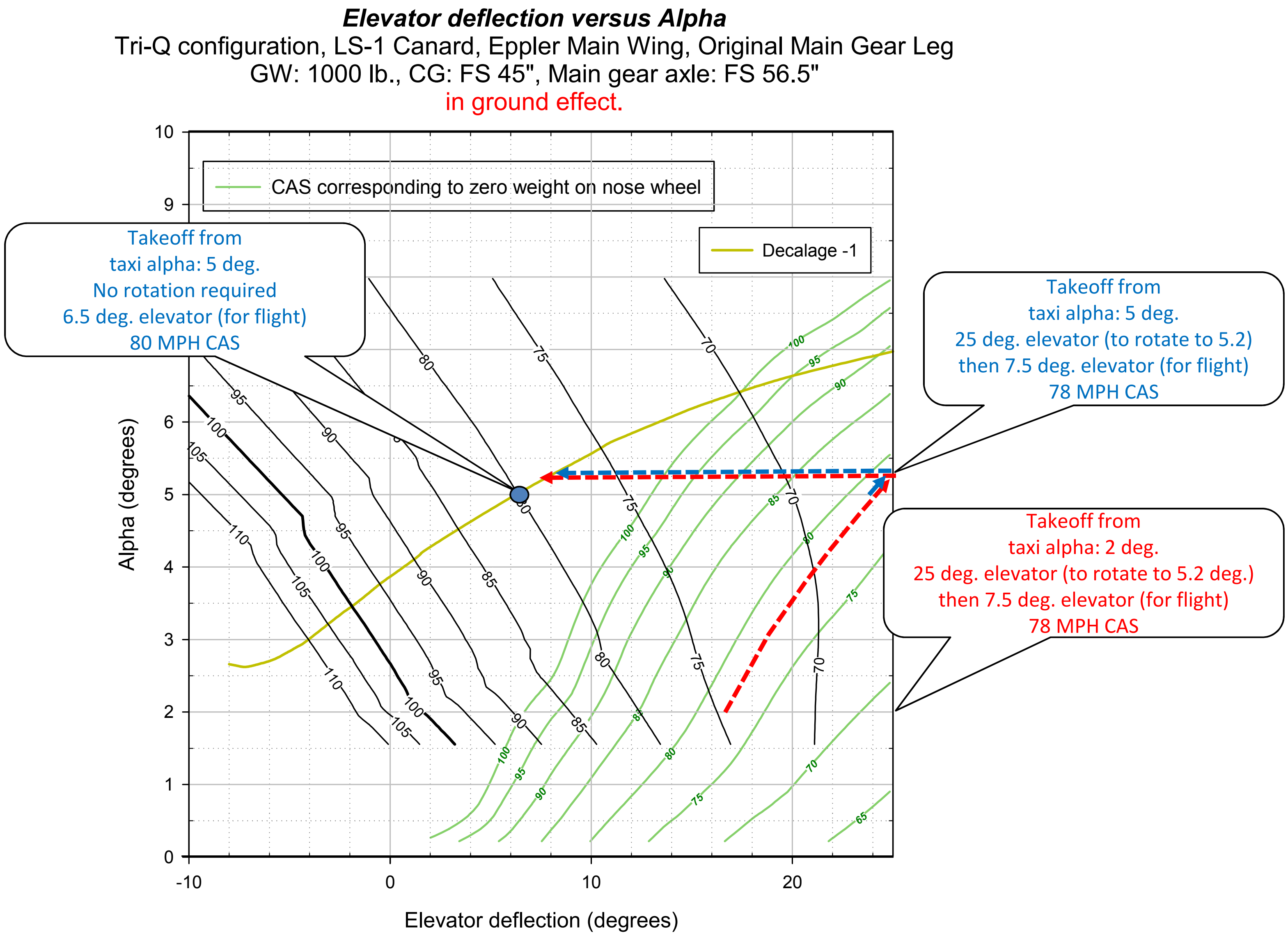


Figure 21. *Take off relationships for Tri-Q200 (decalage -1). If the taxi ground angle is 5 degrees, the Tri-Q200 will rotate to alpha=5.2 degrees and take off at 78 MPH with elevator at 25 degrees to rotate then reduced to 7.5 degrees for flight. The dashed red curve shows the same transition from taxi angle of alpha=2 degrees*

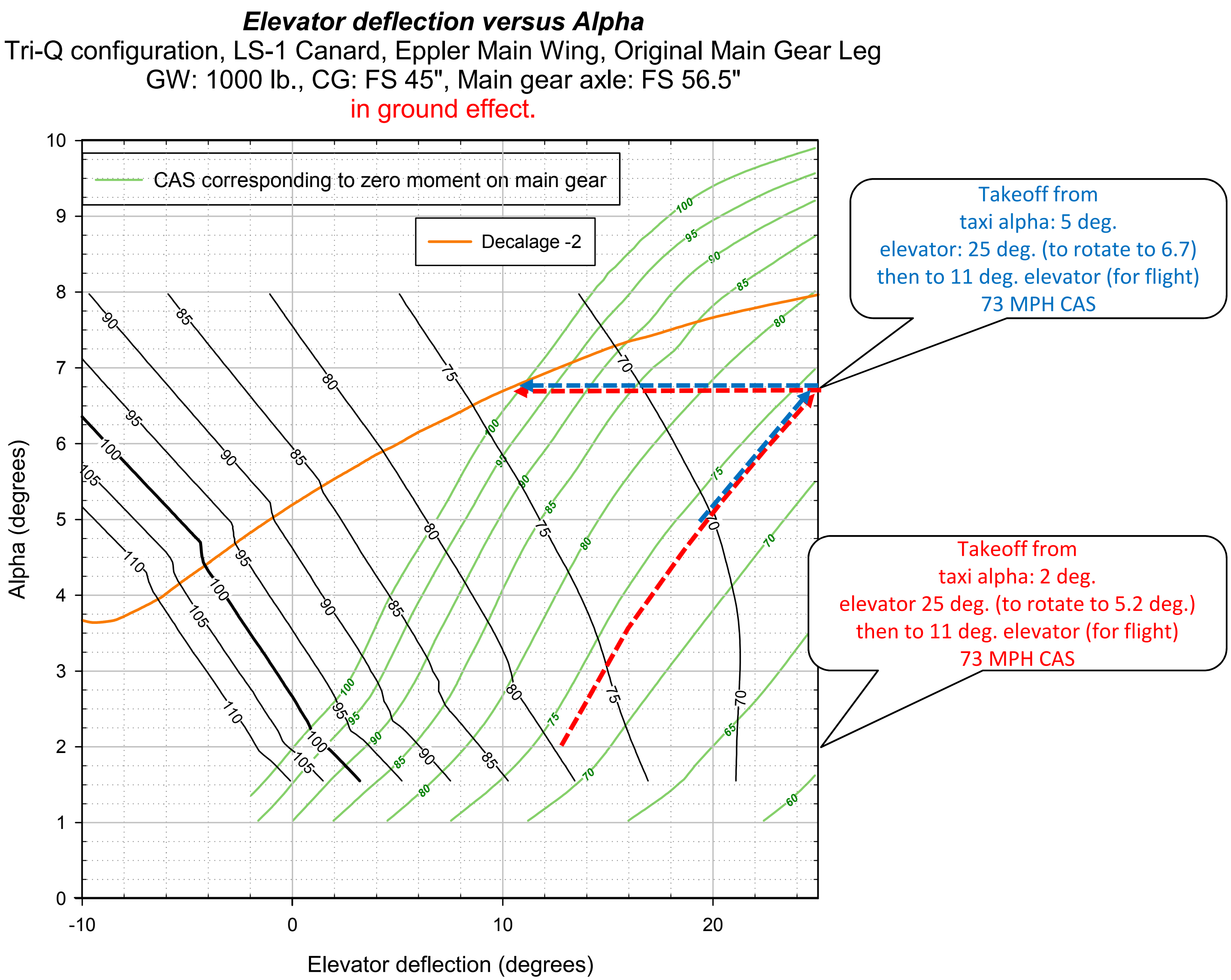


Figure 22. *Take off relationships for Tri-Q200 (decalage -2). If the taxi ground angle is 5 degrees, the Tri-Q200 will rotate to alpha=6.7 degrees and take off at 73 MPH with elevator at 25 degrees to rotate then reduced to 7.5 degrees for flight. The dashed red curve shows the same transition from taxi angle of alpha=2 degrees*

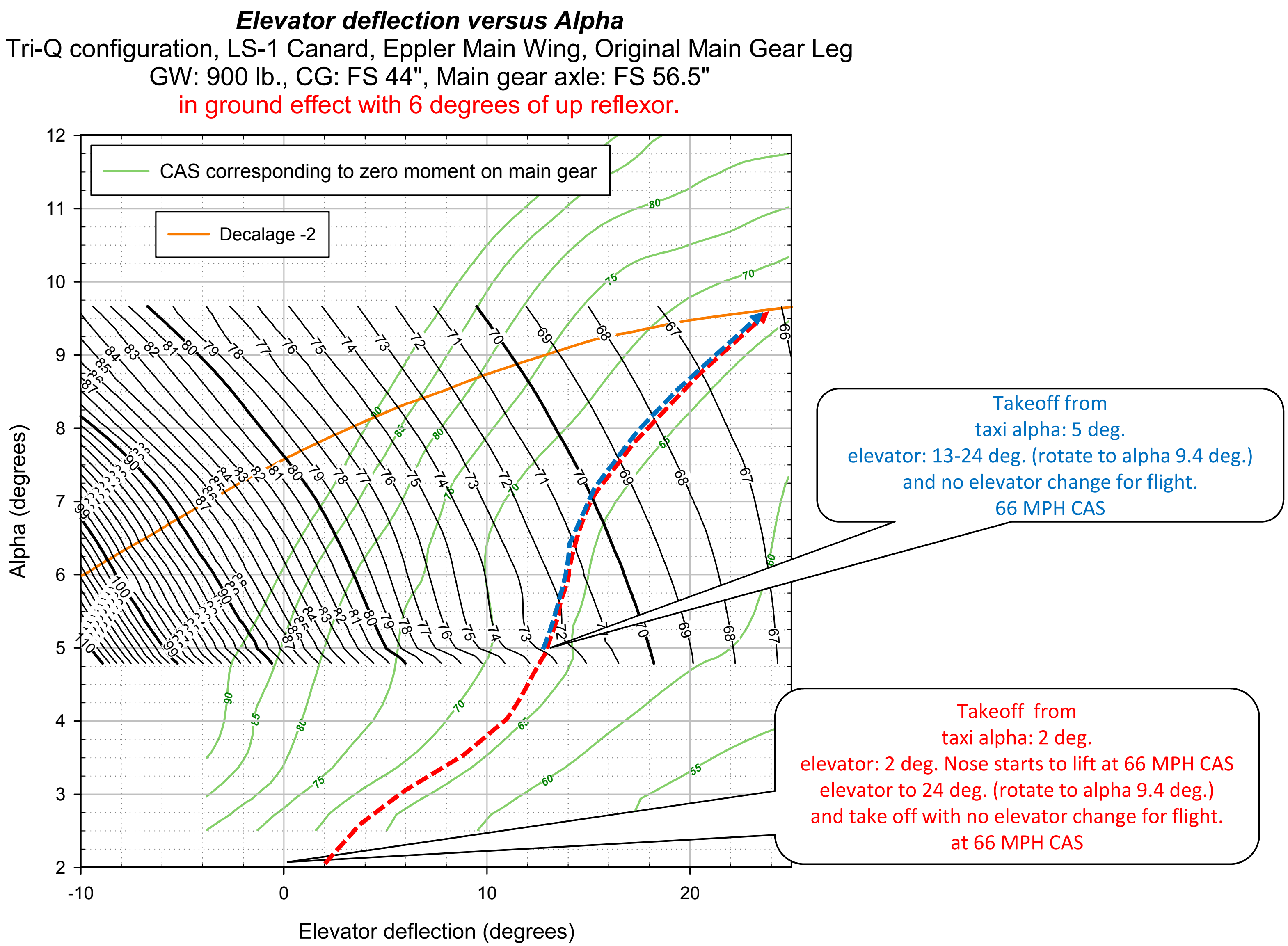


Figure 23. *Take off relationships for Tri-Q200 (decalage -2) with reflexor set to 6 degrees trailing edge up. If the taxi ground angle is 5 degrees, the Tri-Q200 will rotate to alpha=9.4 degrees and take off at 66 MPH with elevator at 24 degrees. The dashed red curve shows the same transition from taxi angle of alpha=2 degrees. The dashed blue curve shows transition from taxi alpha of 5 degrees*