Estimation of the Effect of Lift-drag Ratio caused by Relaxing Longitudinal Static Stability of a certain-type of Joined-Wing Aircraft

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Abstract. According to a given joined-wing aircraft, based on the DATCOM calculation data, under typical cruise and stable hover flight conditions, cases are considered with and without the relaxation of static stability technique. The actual lift-drag ratio of the joined-wing layout and conventional layout is compared and the difference is revealed. This proceeding analyses the reason, seeking the pattern, providing the foundation for the optimization of the overall program of the aircraft in the future.

1. Introduction

Joined-wing aircraft consists of a front wing and a rear wing. Front wing is swept back, and rear wing is swept forward. Rear wing and front wing join at the wingtip or the middle of front wing, forming a frame structure. Compared with the conventional layout, the joined-wing layout has many advantages, such as: lighter weight; higher stiffness; smaller induced resistance; better transonic area distribution; higher maximum trim lift coefficient; smaller wetted area; direct lift and direct side force control; better stability and handling. However, due to the absence of a tailplane far away from the centre of gravity, which the conventional aircrafts usually have, the tail capacity of the rear wings of the joined-wing layout is smaller in the whole aircraft trim calculation. The trim capacity is weaker and the trim loss is larger.[1]

The lift-drag ratio is one of the most important aerodynamic characteristics of the aircraft, which determines the flight performance of the aircraft from the aerodynamic point of view, such as the aircraft's range, stable circling overload and so on. Relaxing the longitudinal static stability is the basic elements in the Control Figured concept. It is effective in improving the lift-drag ratio after trimming. For the joined-wing layout and conventional layout, the same technique of relaxing the longitudinal static stability is adopted, and the lift-drag ratio gain obtained is greatly different. Because the relaxation of longitudinal static stability technique is adopted, higher requirement of the controlling system is needed, e.g. smaller non-sensitive areas and higher speed of the rudder loop, and we need sacrifice some performance to meet our target. It is of great significance to weigh these factors to obtain the satisfying result.[2]

Based on the DATCOM calculation data, under typical cruise and stable hover flight conditions, cases are considered with and without the relaxation of static stability technique. The actual lift-drag ratio of the joined-wing layout and conventional layout is compared and the difference is revealed. This proceeding analyses the reason, seeking the pattern, providing the foundation for the optimization of the overall program of the aircraft in the future.[3]

2. Layout Introduction

A certain type of joined-wing layout aircraft and a conventional layout are selected as comparative models, which in this proceeding set up using DATCOM ; In a typical Mach number, under typical conditions of the longitudinal static stability, the aircraft is trimmed and the lift-drag ratio characteristic is analysed.

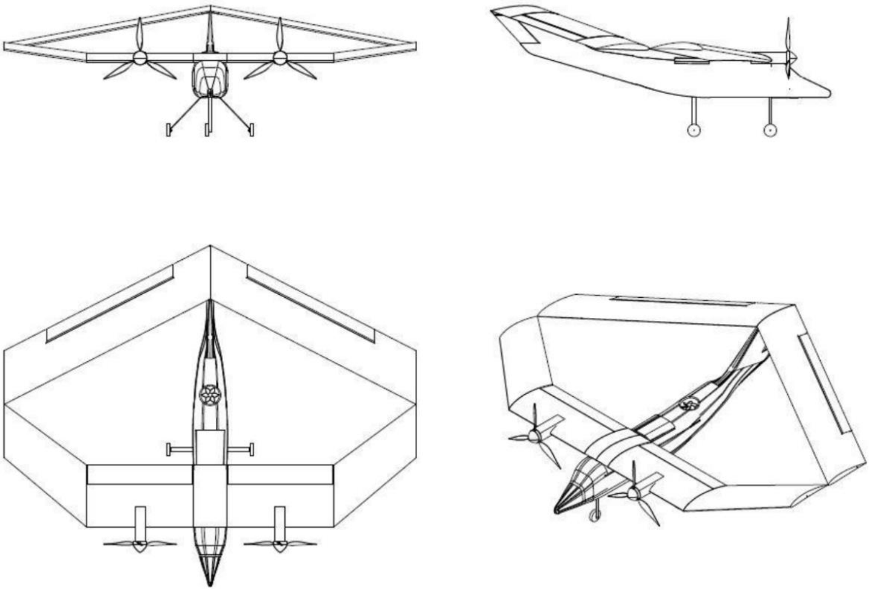

Fig. 1 Three-dimensional view of a certain type of wing aircraft

This joined-wing layout design aircraft is a low-speed general civilian aircraft. In addition to its excellent cruising performance, it also has vertical / short take-off and landing capabilities to facilitate future use in densely populated areas such as cities.[4]

In the design of this joined-wing layout, the "negative staggered" configuration is used, i.e. the low front wing, high rear wing. The inner section of the wing is straight and used to install two power units. Flat straight span airship flaps use double-slit flaps, the slipstream of the propeller covers most of the front wing aerofoils and the trailing edge flaps of the front wings. The high-speed slipstream of the propellers effectively improves the efficiency of the wings and flaps, i.e., the power increase. In the middle of the fuselage behind we adopt a ducted engine layout, to provide upward tension in the vertical take-off and landing mode, to achieve hover and short take-off and landing capability.

When short take-off flap large angle deflection, both maximum engine thrust, a high-speed propeller slipstream effectively delays the flow separation, which greatly improved the effectiveness of the flap section at low speed. Coupled with the effects of deflected slipstream, the aircraft can achieve greater short take-off and landing performance at lower speeds than the conventional take-off and landing and larger head-up torque. However, due to the propeller slipstream cannot effectively affect the rear wing, power lifting part is far from the focus. The focus moves forward in the short take-off and landing mode, aircraft static stability margin and aircraft stability both decreased. The relaxation of static stability control technology is thus needed.

Compared with the existing vertical / short take-off and landing aircraft, the joind aircraft has no tilting mechanism and no cyclic pitch mechanism. As the wings are interconnected and supported, the strength design requirements and the weight of the aircraft are greatly reduced,. Wing-lined aircraft are interconnected by front and rear wings, which helps to increase the structural rigidity of the wing and withstand greater wing loads and prevent wing flutter. Its aerodynamic characteristics often have a higher lift-drag ratio than the conventional layout, improving aircraft take-off and landing performance.

3. Select the Flight Status

In the flight performance of the aircraft, the lift-drag ratio is most closely related to the circling performance and cruising performance. This paper mainly studies the flight performance during the cruise phase. Therefore, several typical flight conditions are selected as the research focus. Because in addition to trim the aircraft using rear wing, we can also use the front wing flaps. The wing flaps trim participate in each state were thus analyzed.

Table 1 Shape and Performance

Shape and Performance	Data
Empty weight (kg)	900
Maximum take-off weight (kg)	1500
Wing reference area (m 2)	30
Wingspan (m)	11
Body length (m)	8.5
Design cruise speed (km / h)	270
Design maximum speed (km / h)	300

Table 2 Flight Conditions

Code	Status	Speed(km/h)	Flap	Lift coefficient	Height
Case1A	Take-off	100	15°	1.0368	0
Case 1B	Short take-off	66	60°	2.38	0
Case 2A	Slide down	120	15°	0.882	2000
Case 2B	Slide down	100	30°	1.1432	1000
Case 2C	Landing	85	45°	1.435	0
Case 3A	Cruise	225	0°	0.276	3000
Case 3B	Favourble speed	136	15°	0.75	3000
Case 3C	Favourble speed	126	30°	0.88	3000
Case 4A	Circling	225	0°	0.414	3000
Case 4B	Circling	225	15°	0.414	3000
Case 4C	Circling	225	30°	0.414	3000
Case 5	Maximum speed	300	0°	0.1552	3000

To assess the gains of relaxing longitudinal static stability obtained, we use five kinds of longitudinal static stability values. In this paper, we choose SLS1 as the general design index of the static stability aircraft, SLS2 ~ SLS5 gradually abandon the natural stability and gradually relax the static stability. However, in short take-off and landing mode, due to the lifting module away from the focus position leads to the whole aircraft Aerodynamic focus moving forward, the longitudinal static stability is decreased.

Table 3 Static Stability Margin

Code	SLS1	SLS2	SLS3	SLS4	SLS5
%	40	30	20	10	0

4. Lift-Drag Ratio Gains

The article defines the lift-drag ratio gain (LDRG) as: $(K_{trimmed}-K_{untrimmed})\div K_{untrimmed}\times 100\%$[5]

Table 4 LDRG of Joined-Wing Aircraft

Static stability margin	SLS1	SLS2	SLS3	SLS4	SLS5
Case 1A	-0.53	0.66	1.85	3.04	4.22
Case 1B	1.88	3.73	5.77	7.7	9.53
Case 2A	1.43	2.39	3.37	4.32	5.28
Case 2B	3.43	4.25	5.08	5.90	6.71
Case 2C	2.24	3.53	4.91	6.22	7.54
Case 3A	-0.77	-1.33	-1.88	-2.25	-2.56
Case 3B	1.62	1.96	2.30	2.62	2.93
Case 3C	7.24	6.66	6.06	5.42	4.79
Case 4A	-0.15	-1.00	-1.80	-2.33	-2.70
Case 4B	4.18	4.07	3.96	3.84	3.73
Case 4C	12.02	14.35	16.68	18.98	21.27
Case 5	-0.85	-1.17	-1.49	-1.82	-2.14

Table 5 LDRG of Conventional Aircraft

Static stability margin	SLS1	SLS2	SLS3	SLS4	SLS5
Case 1A	-12.25	-11.26	-10.31	-9.49	-8.74
Case 1B	-	-	-	-	-
Case 2A	-13.60	-12.71	-11.84	-10.95	-10.03
Case 2B	-17.34	-15.56	-13.57	-11.21	-9.56
Case 2C	-	-	-	-	-
Case 3A	-4.62	-3.59	-2.30	-1.18	0.34
Case 3B	-	-	-	-	-
Case 3C	-	-	-	-	-
Case 4A	-11.09	-10.15	-9.24	-8.64	-7.76
Case 4B	-	-	-	-	-
Case 4C	-	-	-	-	-
Case 5	-4.31	-3.16	-2.13	-1.06	0.22

5. Lift-Drag Ratio Gain (LDRG) Analysis

As can be seen from the above two tables:

Conventional aircraft in the longitudinal stability, the lift-drag ratio gains are negative, and increase after relaxing the longitudinal stability. In the case of a joined-wing aircraft flying at high speeds without flaps, the LDRG is negative, and decreases as the longitudinal stability decreases. When the aircraft uses wing flaps, front wing's lift increases greatly and lift-drag ratio gain improves significantly, but pattern is not obvious which is needed to study carefully

For the determination of the aircraft program, the LDRG of both cases can be quantified. The corresponding data in Table show the difference of LDRG of SLS 5(longitudinal static instability)and SLS1 (longitudinal static stability), which represent the LDRG caused by relaxation of longitudinal static stability.

Table 6 Profit of Relaxing Static Stability

Code	A(joined-wing)	B(conventional)
Case 1A	4.75	3.51
Case 1B	7.65	-
Case 2A	3.85	3.57
Case 2B	3.28	7.78
Case 2C	5.3	-
Case 3A	-1.79	4.96
Case 3B	1.31	-
Case 3C	-2.45	-
Case 4A	-2.55	3.33
Case 4B	-0.45	-
Case 4C	9.25	-
Case 5	-1.29	4.53

As can be seen from the above table:

(1) In the discussions of the cases, the relaxation of the longitudinal static stability changes from SLS1 to SLS5, Scheme A's LDRG, in which case used trim flaps, is increased by -2.55% ~ 7.65% than the non-trimmed case

(2) In the discussions of the cases, the relaxation of the longitudinal static stability changes from SLS1 to SLS5, Scheme B's LDRG, is increased by 3.33% to 7 than the non-trimmed case.

At a height of 3000m,with the aircraft flying stationarily, the relation between LDRG and speed shows below. The static stability changes from 40% to 0%

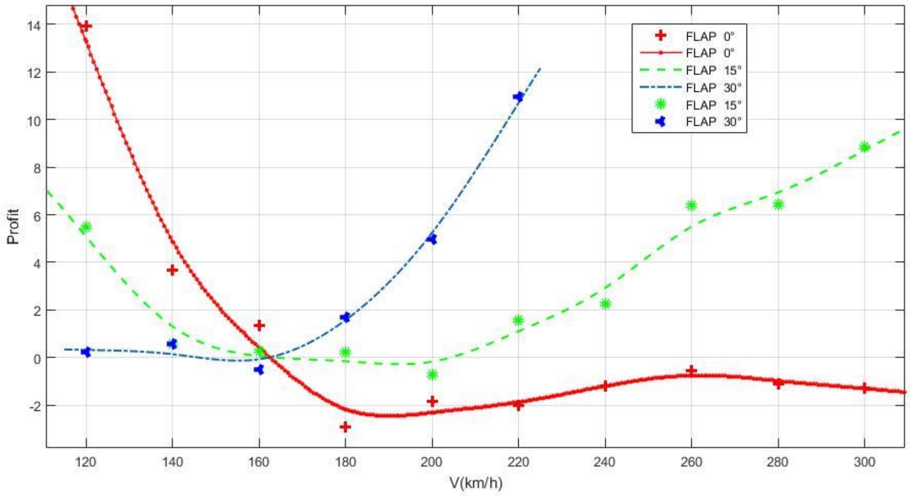

Fig. 2 The relationship between the LDRG and the speed

From the figure we can see:

(1) Without wing flaps, relaxing the static stability at low speeds gives a very large LDRG, but as the speed increases, the LDRG dropped to around -2%.

(2) With 15 ° wing flaps, the LDRG decrease first and then increase with increasing speed.

(3) In the case of 30 ° wing flaps, the benefits of relaxed static stability are small at low speeds but increase rapidly with increasing speeds, but because flaps are not suitable in this case and lift-drag ratio is too low to be taken as reference

(4) In the case of a 15 ° wing flap, trim may be partially analogized to the front wing, which is very effective for wing aircraft lacking a control surface away from the centre of gravity. If the flaps of the front wings are made fully movable and trimmed, it is expected to achieve higher profits.

In Figure 2, we can see that the factors influencing the static stability of relaxation are very complicated. The best choice for the joined-wing aircraft is not when the static stability margin is at lowest. Then looking for a suitable static stability margin is a very important task, the following figure is maintained at 3000m stationary flight, without the use of wing flaps, the relation between LDRG of 5 cases and flight speed is shown below:

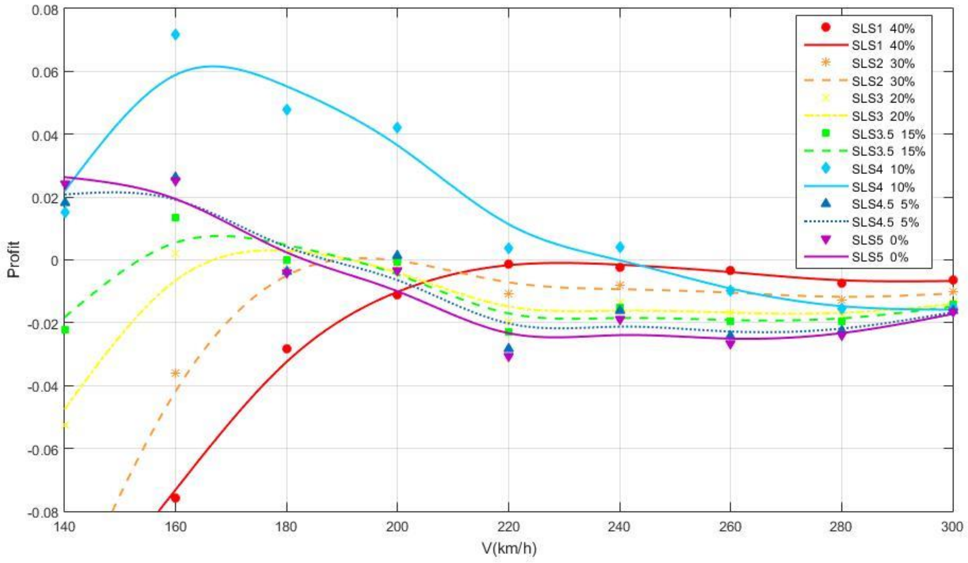

Fig. 3 The relationship between the LDRG and the speed

From the figure we can see:

At a speed below 240 km/h, the trimmed LDRG of the 10% static margin is positive and yields the maximum. While 5% or 15% of the revenue has declined. For this joined-wing aircraft, the trimmed LDRG obtained by 10% of the static margin is higher than other cases.

6. Summary

In summary, relaxing the longitudinal static stability is an important part of active control technology, which can increase the lift, reduce drag and improve the range of conventional aircraft. But when it is applied to the joined-wing aircraft, although the lift-drag ratio at low speed can be significantly increased, the benefits are caused by multiple factors, in which case we cannot blindly reduce static stability margin.

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