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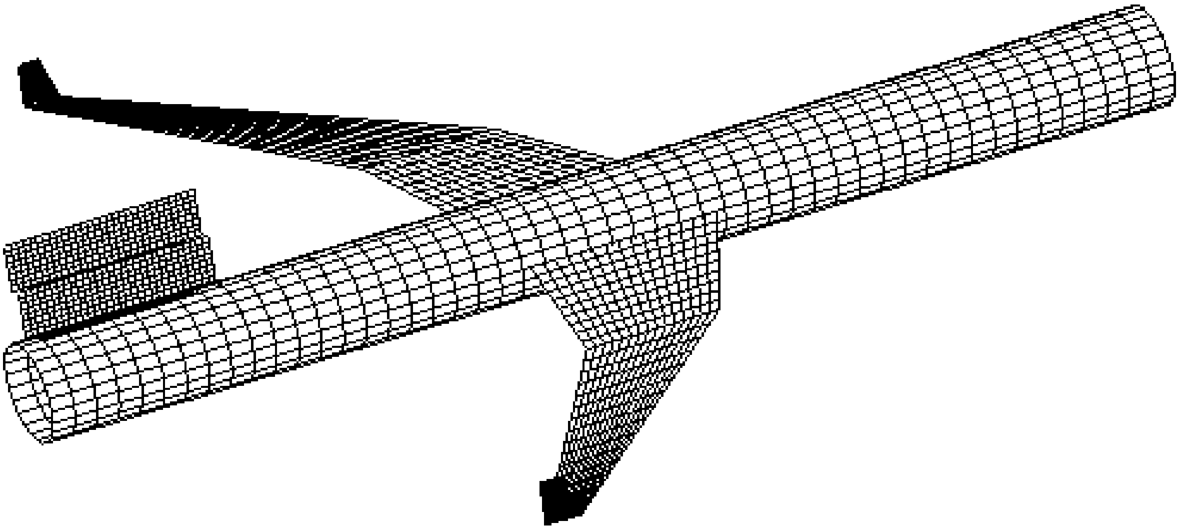
Pilot paper



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Abstract

This pilot paper presents a tailless aircraft configuration that is a realistic alternative to a conventional configuration for a commercial aircraft.

The advantage of this tailless aircraft compared to a conventional one is a reduction in both parasite and induced drag. It can thus operate more economically.

This Tailless aircraft concept have the same longitudinal and directional stability as an MD-81, the aircraft used for reference. Directional stability is to a great extent provided by the two engine nacelles that are placed on top of each other at the rear part of the fuselage.

For longitudinal trim and control the Tailless aircraft concept uses a swept wing that positions the outboard control surfaces well behind the center of gravity which enables them to work as elevators. Combined with the use of thrust vector control (TVC) the trim and control authority in pitch is equivalent to that of the reference aircraft. It can thus handle the same center of gravity envelope and can be operated in the same manner.

Directional control is provided by TVC, with the optional use of winglet rudders or split flaps for yaw control.

The control authority is thus the same for the Tailless aircraft concept as for the reference aircraft in all directions, and from a pilot's point of view there should be no difference between flying a tailless or a conventional aircraft.

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1 Introduction

The idea of a tailless commercial aircraft was presented at the European Symposium on Advanced Aircraft Concepts at Airbus Industrie in Toulouse, November 16-17, 1999.

In spring 2000 some calculations were made by students at KTH, the Royal Institute of Technology, in Stockholm, Sweden as part of an aircraft design exercise [1].

A tailless aircraft should have the same longitudinal and directional stability as a conventional configuration. It should also be able to handle the same center of gravity envelope and have equivalent control authority in all directions.

The basic idea first presented was to remove the fin and horizontal stabilizer and sweep back the wing so that the outer control surfaces were positioned far aft of the center of gravity and could act as elevators. A pair of winglets were placed at the wing tips to provide directional stability and to reduce the induced drag.

However, increasing the sweep of the wing increases the induced drag and have a negative impact on the drag reducing effects of the winglets. Therefore, such a configuration will be less effective than a conventional one.

Another possible idea is to remove the vertical and horizontal tail and replace its control authority by thrust vector control (TVC). The maximum thrust of a normal commercial aircraft is however not high enough to fully allow for trim and control with TVC only.

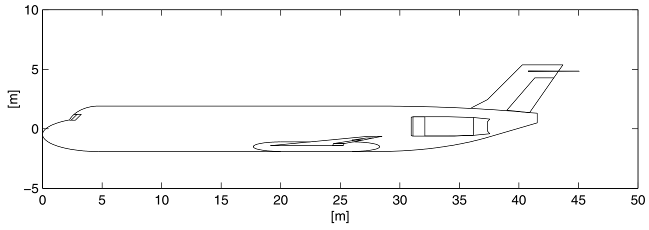
The concept presented here combines the effects of a wing with more normal sweep and the use of TVC. Together these features can give the same control authority as the tail of a conventional aircraft configuration and still reduce both parasite and induced drag.

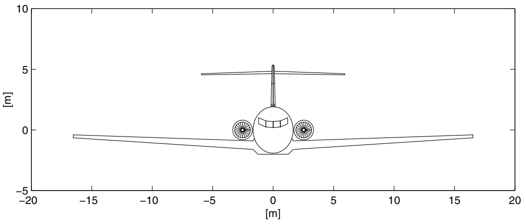
Directional stability is mainly provided by the engine nacelles that are placed on top of each other far aft on the fuselage. Additional directional stability is provided by the winglets that are positioned behind the center of gravity.

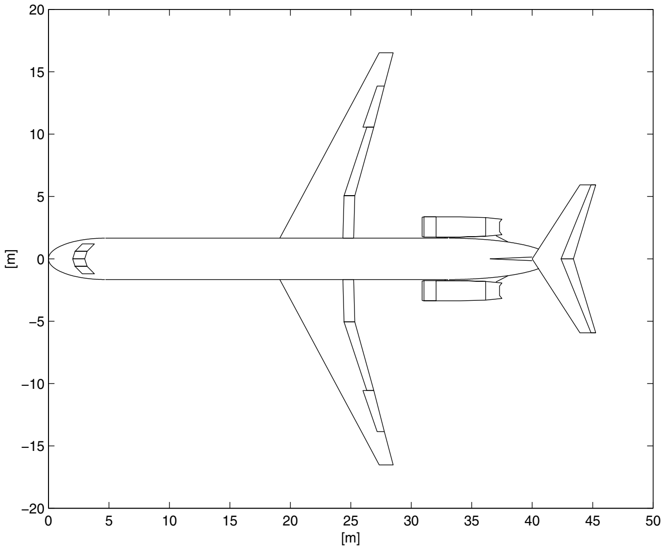
2 Reference aircraft

As a reference aircraft the MD-81 was chosen, mainly since it has the engines mounted on the aft part of the fuselage and has a relatively small fin. It would therefore be a suitable baseline when studying a tailless aircraft concept.

The MD-81 has a fuselage length of 41.30 m and a maximum seating capability of 172 passengers. The engines are two Pratt & Whittney JT8D-209 with a maximum thrust of 90 kN each.



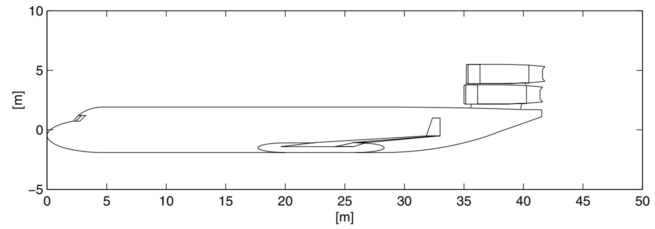


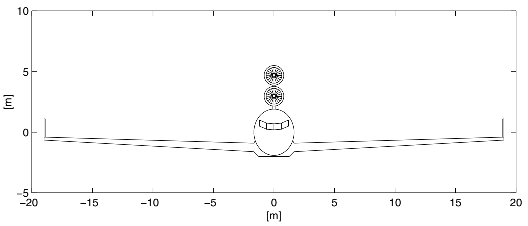


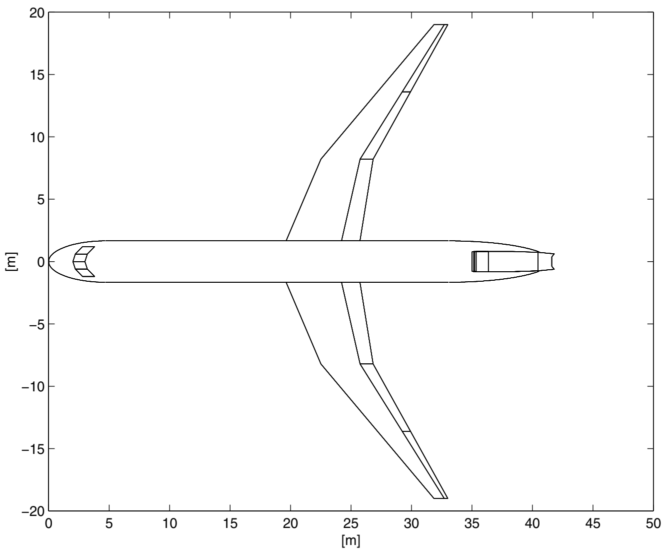
3 Tailless aircraft concept

The illustrated tailless commercial aircraft concept has been studied and evaluated using panel method calculations [2] (see cover picture for example of wing and interference cylinder) and engineering methods. The fuselage and the engines are the same as for the reference aircraft. The mounting of the engines on top of the fuselage provides a great part of the directional stability required for this type of aircraft without adding wetted surface. This mounting position could prove to be structurally challenging and an issue from a maintenance point of view.

The inboard control surfaces shown in the figure are flaps used for high lift. The middle and outboard controls are elevons that can produce moments in both roll and pitch. The middle elevon can also be designed to have a split flap function if this is needed for additional directional control.







3.1 Design of a tailless commercial aircraft

A first approach to designing a tailless commercial aircraft could be to sweep back the wings so that the wing tips would be positioned far aft of the center of gravity. The outer control surfaces could then act as elevators. A pair of winglets placed at the wing tips would also be far aft of the center of gravity and would therefore give the aircraft directional stability as well a reduction of induced drag. The winglets would be equipped with control surfaces to provide the aircraft with directional control, possibly together with split flaps.

A highly swept wing will however cause some difficulties. Apart from structural issues a highly swept wing will have higher induced drag than an equivalent straight wing with the same span and aspect ratio. The winglets will also be less effective and therefore the gain in aerodynamic efficiency rapidly decreases with sweep angle causing the tailless concept to be less effective than a conventional aircraft. It is therefore important to keep the sweep to more moderate values.

3.2 Thrust Vector Control (TVC)

The use of TVC allows the Tailless aircraft concept to have reduced aerodynamic control efficiency in pitch and yaw and therefore allows a lower sweep angle of the wing. Reducing the sweep decreases the induced drag and other problems connected with highly swept wings and makes the tailless concept more attractive.

When considering TVC it should be taken into account that one engine could be inoperative at any time, thereby reducing the control effectiveness of TVC. The aircraft should also have enough control power left to make an emergency decent and landing when both engines have failed.

On a normal commercial transport aircraft the engines do not use enough thrust, e.g. during approach and landing, to allow replacement of the horizontal stabilizer by TVC only. However, it gives enough added control efficiency to enable a reduction in aerodynamic pitch control authority, and thus wing sweep, on the Tailless aircraft concept.

When deflecting the thrust up- or downwards (and sidewards) the forward component will decrease somewhat which has to be taken into account when comparing the different aircraft.

The TVC will be more effective the further behind the center of gravity the engines are positioned. They are therefore mounted as far aft on the fuselage as possible from a structural point of view. The moment arm of the TVC is approximately the same as that of the vertical and horizontal tail on the reference aircraft.

The moment produced by TVC is dependent only on engine thrust and not on dynamic pressure like aerodynamic controls are. TVC is therefore relatively more efficient at low dynamic pressures, like in take-off and landing.

4 Results

4.1 Stability

Longitudinal and directional static stability is the same for the Tailless aircraft concept as for the MD-81. Longitudinal dynamic stability is considerably less than that of the reference aircraft. A modern fly-by-wire computerized control system should however be able to handle this without problems.

Directional stability is to a great extent provided by the two engines mounted on top of each other on the rear part of the fuselage. The remaining stability needed in this direction is provided by the winglets. Using the vertical surface as winglets instead of a small fin on top of the engines helps to reduce the induced drag.

4.2 Trim and control

The trim and control authority in all directions is approximately the same for the Tailless aircraft concept as for the MD-81, even when one engine has failed and reduced the effect of TVC. At engine failure conditions the Tailless concept might not fly in an economic optimal way but this should be of less importance since under normal conditions both engines should work properly.

4.2.1 Trim and control authority in pitch

The horizontal tail on the MD-81 can be deflected as an all-moving surface for trim. It can operate between approximately +2° and -15° and is thus very powerful for longitudinal trim. It must however be able to trim the aircraft at low speeds using aerodynamic forces which demands its large size. The Tailless aircraft concept largely uses TVC for trim which is not affected by low dynamic pressures.

The reference aircraft is assumed to have a minimum static stability margin of 10% and a longitudinal center of gravity envelope from 10% to 28% of the mean aerodynamic chord. This is what drives the trim capabilities of the Tailless aircraft concept.

Trim and control in pitch for the Tailless aircraft concept is provided by the outer control surfaces on the wing and by TVC. The elevon effectiveness in pitch is approximately 35% of the effectiveness of the MD-81 elevator. For trim the MD-81 can use its horizontal tail as an all-moving surface, and compared to this trim capability the outboard control surfaces on the Tailless aircraft concept has about 27% of its control effectiveness.

It is therefore necessary to improve trim and control authority in pitch with the use of TVC. In all cases one engine is considered to have failed.

4.2.1.1 Take-off

At take-off conditions the engines are operated at maximum thrust and the effectiveness of TVC, pitching moment per degree, after the failure of one engine at take-off speed is about 33% of the MD-81 elevator and 26% of the all-moving horizontal tail. The TVC can however operate at larger angles than the control surfaces on the MD-81 and, combined with the elevons, give more trim and control power in pitch than the tail of the reference aircraft.

There is no significant loss in forward thrust due to the thrust deflection, except maybe at rotation where maximum pitch control is used which results in a loss of 5-8%.

A challenge with a tailless aircraft is the nose-down pitching moment normally produced when deflecting the high-lift system during take-off and landing. This moment has to be trimmed with TVC or the elevons, either one producing negative lift and increased drag. One way of reducing this problem is to design the wing so that the additional lift from the high-lift system is located close to the center of gravity, thereby reducing the need for extra trim. The flaps on the Tailless aircraft concept have about the same effectiveness as for the reference aircraft and the additional lift only produces a small nose-down pitching moment.

4.2.1.2 Cruise

At cruise conditions the dynamic pressure is about 4 times higher than at take-off and landing. The use of TVC is therefore relatively less efficient here. The need for trim can be satisfied completely by using only the aerodynamic control surfaces or in a combination with TVC, depending on the most economic setting. Control requirements in normal cruise are assumed to be smaller than in take-off or landing and the elevons combined with TVC can handle pitch control of the aircraft along with trim without problems.

4.2.1.3 Landing

At final approach and landing the dynamic pressure is relatively low which gives TVC an advantage over aerodynamic control surfaces. The engines are however normally only operated at about 30% of maximum thrust during this flight phase. If one engine fails this should not cause additional problems since the remaining engine can operate at 60% of its maximum thrust, or more to compensate for deflection, and thus keep the total thrust at a constant level.

The trim and control requirements when landing is similar to those at take-off, only with reduced thrust. This means that the thrust has to be deflected at a larger angle to give an equivalent normal force and thus pitching moment. This is the most critical flight case for the TVC and with the center of gravity in the most forward position combined with maximum nose-up pitch control the TVC is used at 35° which is set as the maximum deflection angle. Then the elevons need a deflection of about 8° to account for the rest of the control need.

4.2.2 Control authority in roll

Control in roll is provided by elevons, and if necessary with the assistance of spoilers in the same way as on the reference aircraft. Because of the slightly larger span on the Tailless aircraft concept the roll control is somewhat more efficient to compensate for the larger rolling moments.

Thanks to the rather small deflection of the elevons as elevators there is enough control authority left for roll control.

4.2.3 Control authority in yaw

Some of the control power of a two- or more engine aircraft is usually needed to counteract the yawing moment produced by asymmetric thrust. By placing the engines above the centerline of the aircraft this problem will be avoided and control in yaw is only necessary to handle the aircraft, e.g. when landing in strong cross winds.

There are three ways of providing directional control on the Tailless aircraft concept. One is the use of TVC also in this direction. A deflection angle of 22° in landing conditions give the same yawing moment as a 20° deflection angle of the rudder on the MD-81. If added control authority is needed in yaw, for example if TVC should be used only for pitch control, the winglets can be equipped with control surfaces or be deflected as all-moving surfaces. Split flaps located at the trailing edge of the wing produce yawing moment by increasing the drag on one side of the aircraft.

4.3 Drag

The wing area on the Tailless concept aircraft is the same as the wing and stabilizer areas combined on the MD-81. The friction drag should therefore not be higher, but instead probably lower due to higher average Reynolds number over the wing. The winglets on the Tailless concept aircraft are much smaller than the fin on the MD-81 which means a reduction in total wetted area.

The form drag should also be somewhat lower for the wing and winglets on the Tailless aircraft concept than for the wing, fin and horizontal stabilizer on the MD-81.

Induced drag at trimmed conditions is lower on the Tailless aircraft concept than on the MD-81, partly due to the larger span and partly because the vertical surfaces are used as winglets instead of a fin.

4.4 Weight

The weight of the Tailless aircraft concept is assumed to be the same as that of the reference aircraft. Deleting the vertical and horizontal tail is assumed to be compensated for by increased structural integrity needed for the mounting of the engines, together with the larger sweep and span of the wing used on the Tailless aircraft concept. Also the weight of the TVC mechanism has to be accounted for.

5 Conclusions

The benefit of this Tailless aircraft concept compared to a conventional configuration is a reduction in both parasite and induced drag at cruise which makes it more economic to operate.

Longitudinal and directional stability is the same for the Tailless aircraft concept as for a MD-81, which is used for reference. Directional stability is mainly provided by the engine nacelles that are positioned on top of each other far aft on the fuselage, acting as a vertical tail without adding wetted area. Additional stability in yaw comes from the winglets.

The Tailless aircraft concept has the same trim and control capabilities in all directions as the reference aircraft. It uses the combination of TVC and a swept wing that positions the elevons well behind the center of gravity for longitudinal trim and control. Lateral control is provided by the elevons and spoilers in a conventional manner while directional control is produced by TVC, possibly in combination with winglet control surfaces and split flaps.

From an operational point of view the Tailless aircraft concept should be just as flexible to use as a conventional design, but more economic.

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[2] Gustavsson A., *A computer program for the Prediction of Aerodynamic Characteristics of Wing-Body-Tail Combinations at Subsonic and Supersonic Speeds*, FFA Report AU-635, Part 2, Stockholm, Sweden 1972.

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Abstract

This pilot paper presents a tailless aircraft configuration that is a realistic alternative to a conventional configuration for a commercial aircraft. The advantage of this tailless aircraft compared to a conventional one is a reduction in both parasite and induced drag. It can thus operate more economically.

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Keywords
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Rapporttitel

Ett stjärtlöst flygplanskoncept

Sammanfattning

I detta “pilot paper” presenteras ett stjärtlöst flygplanskoncept, utan konventionell fena och stabilisator, som är ett realistiskt alternativ till en konventionell transportflygplanskonfiguration. Fördelen med detta koncept jämfört med ett konventionellt flygplan är en minskning av både nollmotstånd och inducerat motstånd. Den blir därmed mer ekonomisk att använda.

Detta flygplanskoncept har samma tipp- och girstabilitet som en MD-81, som används som referensflygplan. Det största bidraget till girstabiliteten kommer från de två motorerna som sitter ovanpå varandra långt bak på kroppen.

För trim och styrning i tippled använder detta flygplanskoncept en svept vinge som placerar de yttre styrytorna en bra bit bakom tyngdpunkten vilket gör att dessa kan användas som höjdroder. I kombination med dragkraftsvektorisering (TVC) så blir trim- och styrförmåga i tippled samma som för referensflygplanet. Man kan därför hantera samma tyngdpunktsenvelopp och flygplanet kan användas på samma sätt. Styrning i girled görs med TVC, med möjlighet att även använda roder på winglets eller splitklaffar på vingarna.

Styrförmågan i samtliga riktningar är alltså samma för detta flygplanskoncept som för referensflygplanet, och ur en pilots synvinkel bör det inte vara någon skillnad mellan att flyga ett stjärtlöst eller ett konventionellt flygplan.

Nyckelord

stjärtlös, kommersiellt, flygplan, dragkraftsvektorisering, TVC

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