Aircraft Family Concept for High Subsonic Transport Aircraft

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Abstract: - The objective of this work is to make a feasibility study of the aircraft family concepts using a combined Hybrid Laminar Flow Control - Variable Camber Wing (HLFC-VCW) for a high subsonic Advanced Technology Regional Aircraft (ATRA). The prediction of ATRA’s performance used computational fluid dynamic and empirical methods. The aircraft family concept using a combined HLFC–VCW is feasible for ATRA aircraft family from aerodynamic point of view.

Key-Words: - Aircraft family concept, high subsonic transport aircraft, hybrid laminar flow control, variable camber wing, aerodynamics, aircraft design, advanced technology, regional aircraft.

1 Introduction
In order to increase their profit, many Aircraft manufacturers, i.e.: Airbus, Boeing, McDonnell Douglas, Fokker, British Aerospace, IPTN/I Ae, etc., have developed their aircraft family based on one wing and one fuselage cross section to reduce development costs. For one fuselage cross section aircraft family, alternatives concepts for Regional Airliner family are:
1. fixed wing geometry on mid-size, then direct operating cost (DOC) penalties for off- optimum,
2. fixed wing geometry on mid-size, modification of wing extension/reduction, then development costs, and
3. Variable Camber Wing (VCW) which could be optimum for all family, but will have increased development costs.

The objectives of this work is to improve the current aircraft family performance using the application of new technology (i.e.: HLFC and VCW).

2 ATRA Initial Baseline Design
The following section describes in brief the design methodology for conceptual sizing of aircraft based on the author’s experience when he worked as an aircraft configurator for IAe (Indonesian Aerospace).

2.1 Design Requirements and Objectives
As a successor of the regional jet, the baseline (ATRA-100) will offer 108 seats in two class layout, while the stretched (ATRA-130) and shortened (ATRA-80) versions are accommodate for 133 seat in two class layout and 83 seat in two class layout respectively. The cost-economic cruise speed was set at M = 0.8 at a nominal range of 2,250 nm (ATRA-100), 2,000 nm (ATRA-80) and 2,500 nm (ATRA-130). For all versions the maximum approach speed will be 127 knots.

2.2 Initial Sizing
Using a sizing method [1], the main parameters of initial sizing of the three versions are as follow:

<table>
<thead>
<tr>
<th></th>
<th>ATRA-80</th>
<th>ATRA-100</th>
<th>ATRA-130</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTOW (kg)</td>
<td>45,538</td>
<td>56,260</td>
<td>69,576</td>
</tr>
<tr>
<td>T/W</td>
<td>0.291</td>
<td>0.291</td>
<td>0.291</td>
</tr>
<tr>
<td>W/S (kg/m²)</td>
<td>413.2</td>
<td>510.5</td>
<td>631.3</td>
</tr>
</tbody>
</table>

2.3 General Arrangement
Based on an existing aircraft there are two main types of general arrangement for a regional passenger jet transport aircrafts, i.e.:
1. Boeing, Airbus, IAe type : low-wing, low/fuselage-tail, engine mounted on the wing and tricycle landing gear attached on the wing and stowage on the wing-fuselage fairing.
For this study, general arrangement type 1 in 2.3 is selected for the ATRA-100 baseline configuration, ATRA-80 and ATRA-130, as shown in Fig. 1.

2.4 Aircraft Family Concept.
Fig. 2 shows The ATRA Family concept. Because of wing fuel tank limitations, the payload-range for ATRA-130 can not be achieved. There are several options to solve this problem, namely : (1) increase the wing area and/or thickness, (2) to reduce the ATRA-130 range performance, (3) add fuel on empennage or fuselage tanks, and (4) investigate the use of winglets to reduce induced drag and therefore fuel burn.

There are several options to design the low speed performances of the ATRA-130, namely : (1) use the same wing and high lift devices as the ATRA-100 but with increase in take-off and landing field distance, (2) increase the wing area, and (3) improve the high lift devices performance.

The ATRA-100 has maximum design commonality with the ATRA-80 and ATRA-130. The level of commonality between the members of the ATRA standard-body aircraft family is such that the ATRA-80, ATRA-100 and ATRA-130 can essentially be operated as one aircraft type with positive effects on crew training, maintenance and aircraft scheduling. In addition, a mixed fleet of ATRA-100 aircraft combined with other aircraft in the ATRA family will allow airlines to better match capacity to demand whilst reducing operating costs, increasing crew productivity and simplifying ground handling.

Being the reduced/increased size development of the ATRA-100, the ATRA-80/ATRA-130 key changes are primarily related to size and capacity as all aircraft share similar systems and the same flight deck. Key changes include : derated/uprated engines, adapted systems and two fuselage plugs removed/added.

3 Technology Concepts for ATRA
The main issue in the application of new technologies in transport aircraft is the ability to employ them at low cost without reduction of their benefits. This cost is reflected in the following shares of Direct Operating Costs (DOC) : fuel, ownership and maintenance. Laminar flow - variable camber technology will only produce acceptable DOC if the penalties due to additional weight and the complexity of the system do not exceed those of the fuel savings. Hence the most important objective in realizing advanced laminar flow-variable camber technology is to reduce their additional system costs, weight and minimize maintainability and reliability costs.

3.1 Initial Wing Design.
Performance Objectives.
For a typical jet aircraft, the equation for cruise range (R) can be expressed as :

$$ R = \left( \frac{a_0 \sqrt{\Theta}}{TSFC} \right) \ln \left( \frac{M \ L}{D} \right) \ln \left( \frac{W_{final}}{W_{initial}} \right) $$

where : $a_0$ = speed of sound
$\Theta$ = temperature ratio, $T/T_0$

The equation states that if the thrust specific fuel consumption, TSFC, is considered to be nearly constant (which is usually in the cruise region), a jet aircraft will get the most range for the fuel burned between weights $W_{initial}$ and $W_{final}$ by making the quantity (Mach number)(Lift/Drag), $M(L/D)$, a maximum. The basic aerodynamic performance objective is, therefore, to achieve the highest value of $M(L/D)_{max}$ at the cruise Mach number. Climb and descent performance, especially for short range missions, is also important and may suggest the “cruise” design conditions be compromised.

It is believed that the combined laminar flow - variable camber wing will increase $M(L/D)$ [2 - 4]. However, the off-design considerations must not be neglected. The off-design characteristics should show no drop in lift or $(L/D)_{max}$ at Mach numbers below cruise. The variation of L/D with lift at cruise Mach number should provide at least 95% of $(L/D)_{max}$ for a (+/-) 0.1 variation in lift at cruise [5].

Wing area, planform and airfoil design.
With maximum take-off weight (MTOW) of ATRA-100 = 56,260 kg and wing loading (W/S) = 510.5 (kg/m²), wing area (S) for ATRA-100 = 110.21m².

Wing planform selection is based on a combination of criteria that require constant review during the design phase. Planform span, aspect ratio, sweep, and taper will be revised based on the trade’s studies taking place during the design. As sweep increases, the MTOW, operating empty weight (OEW), mission fuel and engine size increase for a constant aspect ratio and wing loading. As aspect ratio increases, OEW and MTOW increase while engine size and fuel burn decrease.

A detailed trade off study of planform parameters is outside the scope of this work. For ATRA-100
Baseline, sweep and taper ratio are taken based on comparison with existing aircraft data, (Fig. 3) i.e.:

- A quarter chord sweep (\(\alpha_q\)) = 25 deg.
- Taper ratio (\(\lambda\)) = 0.274
- Aspect ratio (AR) = 9.5

The introduction of laminar flow represents an additional design criterion that must be satisfied along with all existing considerations. The issues raised for NLF section design are also relevant to Hybrid Laminar Flow Control (HLFC) sections although leading edge suction reduces the severity of the constraints imposed for NLF. Typically transonic HLFC aerofoil sections have been designed with pressure distributions having a small peak close to the leading edge, followed by a region of increasing pressure (an adverse pressure gradient) over the suction region, after which the ‘roof-top’ has a mildly favorable pressure gradient. Such a pressure distribution has been found to maximize the extent of laminar flow.

For this study, three airfoils were designed, i.e., root, inboard and outboard, as shown in Fig. 4.

### 3.2 The Application of Combined HLFC-VCW

Practical use of HLFC requires that laminar flow be maintained through a range of cruise lift coefficients and Mach numbers. Variations in lift coefficient and Mach number will change the wing pressure distributions from the optimum and may result in some loss of laminar flow. Therefore, it was decided to investigate a HLFC wing together VC-flap. Deflection of the VC-flap permits controlling the pressure distribution over the forward part of the airfoil, keeping it similar to the design pressure distribution, even when the lift coefficient and Mach number differ considerably from the design values. With careful design of VC-flap, it would be possible to reduce the wave drag penalty, and to sustain attached flow in turbulent mode. Flow control on such a wing, is shown schematically in Fig. 5.

**Candidate laminar flow – variable camber section**

Section views of the two wing configurations considered in this study are shown in Fig. 6. Configuration I has both upper and lower surface suction, from the front spar forward with leading edge systems as proposed by Lockheed [6]. Because it has no leading-edge device, it requires double-slotted fowler flaps to achieve \(C_{\text{Lmax}}\) requirements.

Configuration II replaces the lower surface suction with full-span Krueger flaps, which, combined with single-slotted fowler flaps, provide equivalent high lift capability. The Krueger flaps also shield the fixed leading edge from insect accumulation and provide a mounting for the anti icing system. Only the upper surface, however, has suction panels. The leading edge system used on configuration II is similar to leading edge systems as proposed by Douglas [6].

Preliminary estimates [4] indicated cruise drag reductions of about 11% for HLFC having laminar flow on the upper and lower surface, while the reduction for HLFC having laminar flow only on the upper surface was only 7%. The deficiencies noted for configuration I are related to low speed performance and insect contamination problems. The potential exists for high lift performance improvements if wings were specifically designed for the HLFC task. Although it has an inherently lower drag reduction, configuration II is more likely to provide a stable laminar boundary-layer due to a lower likelihood of being contaminated by insects. Taking into account the above considerations, configuration II was selected, for this study.

**Hybrid laminar flow – variable camber section baseline configuration**

The Hybrid Laminar Flow Control - Variable Camber Wing (HLFC-VCW) section baseline configuration for use on the ATRA-100’s wing is shown in Fig. 7.

Ideally the change in section profile at aft of the rear spar should not cause separation of airflow, which would otherwise give rise to higher profile drag. To overcome the problem of separation, the radii of local curvature must be greater than half the chord, but not too high, as the section will have a higher pitching moment, and hence higher trim drag, which then will reduce the benefit of variable camber itself. The radii should be optimized between these two constraints. The radius is inherent to the trailing-edge upper surface of the aerofoil, so when the aerofoil is used for a VC concept, the aerofoil should be designed with taking into account the above considerations from the beginning.

The concept of variable camber used for the ATRA-100’s wing is quite similar to traditional high lift devices. The camber variation is achieved by small rotation motions (in two directions for positive and negative deflections). In VC-operation the flap body slides between the spoiler trailing edge and the deflector door. Camber variation is therefore performed with continuity in surface curvature at all camber settings. During this process the spoiler position is unchanged.
4 Aircraft Performance
The computational design analysis and revision of the ATRA-100 aircraft due to lift/drag improvement from the application of HLFC on the ATRA-100 aircraft compared to the turbulent version will be described in the following section.

4.1 Computational design analysis for ATRA-100’s wing
Fig. 8 and 9 show the contours of static pressure in fully turbulent flow and in fully laminar flow, respectively, both for variable-camber flap deflected, for detailed flow analysis see Reference [3].

4.2 Revision of the ATRA-100 aircraft
Technically, the application of the combine HLFC-VCW to the civil transport aircraft appears to provide significant performance gains in terms of fuel consumption and payload range performance. However, in order to justify the implementation of the technology economically, it is necessary to consider the associated costs throughout the entire program.

It was judged that the most appropriate method of examining the cost implications of the combine HLFC-VCW would be to examine it’s effects on the direct operating costs (DOC) of the aircraft. For the purposes of this research, aircraft weight reductions and increased range performance due to the application of the combine HLFC-VCW would be examine rather than DOC, with the assumption if the aircraft weight is reduced DOC would also reduce.

The aircraft lift/drag improvement at cruise (Mach 0.8, 10,668 m and $R_N = 6.28e^6/m$) was 7.675 % of total cruise drag [3].

Some of the advantages and disadvantages of the application of the combined HLFC-VCW to civil transport aircraft compared to the turbulent version are [3]:
- HLFC systems weight = 0.373 % MTOW,
- VCW systems weight = 0.5 % wing weight,
- Lift/drag increment due to VCW application = 2.5 %,
- The increment in fuel flow to maintain the specified net thrust due to power off-take of HLFC suction systems = 0.2 %,
- Assumption : the reduction of wing sections t/c due to the application of the HLFC is eliminated by the application of VCW and wing sweep is unchanged.

The above values are taken from aircraft which does not closely match of the ATRA aircraft types included in this study, preventing any direct comparisons. However, the benefits and/or drawbacks associated with the various HLFC and/or VCW applications are provided. In the absence of a detailed investigation, it was decided to use the above values.

With the above predictions and assumptions using sizing method [1], it is reasonable to conclude that the benefits of the combine HLFC-VCW to the ATRA-100 aircraft compared to the turbulent version are : (1) for constant DR&O : MTOW reduction = 4.25 % and (2) for constant MTOW : range performance increased by 7.63 %.

5 Conclusions
The aircraft family concept using variable camber wing technology to manage the lift requirement is feasible from technical point of view

The combined HLFC–VCW as a flow control concepts is feasible for a transport aircraft from aerodynamic point of view. With the same reservations that apply to the feasibility of any laminar flow control (LFC) and variable camber flap (VCF) aircraft, i.e. the economic aspects depend on material, manufacturing and operational data. Before HLFC and VCW technology can be applied to the transport aircraft, a large multidisciplinary research effort is needed in order to master the technology and demonstrate it on flying test-beds and in-service operational tests.

Acknowledgments
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References:

Fig. 1. ATRA-100, with additional side views of ATRA-130 (centre) and ATRA-80 (below)

Payload-range concept
trio regional airliner

Fig. 2. The ATRA Family concept

Fuselage concept
two fuselage plugs removed/added

Lift management concept
optimum cruise/climb management
constant altitude cruise management

Fig. 3. ATRA wing concept

Fig. 4. Airfoil for ATRA wing (root, inboard and outboard)

Fig. 5. Flow control on the wing

Fig. 6. Cross sections of candidate combine HLFC-VCW configurations
Fig. 7. HLFC-VCW section baseline configuration

Fig. 8. Configuration II: contours of static pressure, Pascal (fully turbulent flow)

Fig. 9. Configuration II: contours of static pressure, Pascal (fully laminar flow)