Aerodynamic Optimization of an Over-the-Wing-Nacelle-Mount Configuration

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This paper presents the numerical aerodynamic optimization of an Over-the-Wing Nacelle (OWN) configuration with the aim of achieving higher L/D than conventional Under-the-Wing-Nacelle (UWN) configuration. The flow channel between the wing and the nacelle is optimized to prevent the interference effect. In this research, nacelle geometry and its position are firstly focused on to remove unfavorable aerodynamic interference effect between a nacelle and a wing by making use of CFD and optimization methods. Next, the wing shape is also optimized to avoid further aerodynamic interference in addition to the modification of a nacelle. Finally, the pylon shape is optimized to improve the cruise performance. The final optimized configuration achieves higher L/D of 35.5 by Euler solver, and it revealed that the OWN configuration can achieve high aerodynamic performance comparable to the conventional UWN configuration.

Nomenclature

\[ a = \text{sonic speed} \]
\[ A.o.A = \text{angle of attack} \]
\[ C_D = \text{drag coefficient} \]
\[ C_L = \text{lift coefficient} \]
\[ X = \text{distance from the leading edge of the wing to the front face of the nacelle} \]
\[ c = \text{chord length} \]
\[ X/c = \text{front-rear movement parameter of the nacelle} \]
\[ Z = \text{vertical distance from the wing upper surface to the nacelle lower surface} \]
\[ h = \text{diameter of the nacelle} \]
\[ Z/h = \text{vertical movement parameter of the nacelle} \]
\[ L = \text{lift} \]
\[ L/D = \text{lift-to-drag ratio} \]
\[ M = \text{Mach number} \]
\[ \text{ANOVA} = \text{analysis of variance} \]
\[ P = \text{pressure} \]
\[ \mathbf{u} = \text{velocity vector} \]

I. Introduction

With the growth in aircraft traffic, there is a strong demand to reduce the airport noise. The major sources of the airport noise are jet and fan noises caused by the jet engine. The noise levels of a conventional aircraft at takeoff and landing are shown in Fig. 1 [1]. It is obvious that fan noise and jet noise are high level at take-off, while airframe noise and fan noise are dominant at landing. In Europe and the United States, regulations on airport noise have been tightened, thus it is a significant problem to reduce the noises of aircraft, particularly to prevent engine noises.

To reduce the airport noise, several aircraft configurations have been proposed lately. One is to install engine nacelles over the aft fuselage, and another is to install engine nacelles over the wing. In the latter case, successful

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experiences are only a few cases including the recent Honda Business jet [2]. The Over-the-Wing-Nacelle (OWN) configuration is one of the potential approaches to reduce the noise drastically because the wing can block the propagation toward ground caused by fan and jet noises. However, when the engine nacelles are installed over the wing, the aerodynamic performance tends to drop significantly due to the interference effect. If the interference between a nacelle and a wing is avoided and large increase in aerodynamic performance is achieved, OWN configuration will be a potential candidate to be a near-future quiet aircraft configuration.

The purpose of this study is to investigate the aerodynamic feasibility of OWN configuration by making use of Computational Fluid Dynamics (CFD) and optimization methods. The cruise Mach number is set to 0.70 to focus on mid-sized, short-range aircraft for the domestic use. In this study, aerodynamic interference effect between a nacelle and a wing is optimized through the modification of nacelle, wing and pylon shapes. The Kriging model is adopted to build an approximation model of the objective functions to reduce the large computational burden demanded by a stochastic optimization method coupled with 3D high-fidelity CFD computation around a full aircraft geometry. The Kriging approximation model is built on well-distributed sampling points, which can be used as a database to analyze design space. Analysis of Variance (ANOVA) is one of useful statistical tools to investigate the contribution of design variables to objective function. This helps to understand the important factor to avoid the interference.

Firstly, preliminary analyses of OWN configuration are conducted to validate the aerodynamic feasibilities of OWN configuration at cruise condition. Followed with the preliminary results, optimization is conducted to modify engine nacelle position and its shape at Mach 0.70. However, the optimized nacelle is simply located away from a wing to reduce the aerodynamic interference between the nacelle and the wing. It leads that a nacelle has to be placed away from a wing to improve L/D for OWN configurations. One of critical drawbacks of OWN configuration is difficulty in engine maintenance because the engine is installed above the wing. For the easy maintenance activity, engineers should be able to reach engines from the ground. In this sense, a nacelle has to be close to the wing. Similarly, nacelle position for chord direction should not be installed at the aft of the wing, which causes structural problem. For these reasons, the aim of the optimization is to find a design that achieves high L/D without allowing a nacelle to be away from a wing. To accomplish this target, three-dimensional wing shape is also optimized in addition to nacelle position and shape for a realistic OWN configuration. In the optimization, nacelle height and position are also optimized to minimize distance with a wing. Finally, the pylon shape is optimized for further reduction of the unfavorable aerodynamic interference between a wing and a nacelle of the optimized wing-nacelle configuration.

Fig. 1 Noise Level (Left: takeoff, Right: landing)

II. Flow Solver and Optimizer

In this research, three-dimensional flows are analyzed using the unstructured mesh CFD TAS (Tohoku University Aerodynamic Simulation) code [3]. The compressible Euler equations are solved by a finite-volume cell-vertex scheme. The numerical flux normal to the control volume boundary is computed using an approximate Riemann solver of Harten-Lax-van Leer-Einfeldt-Wada (HLLEW) [4]. The second-order spatial accuracy is realized
by a linear reconstruction of the primitive gas dynamic variables inside the control volume with Venkatakrishnan’s limiter [5]. The LU-SGS implicit method for unstructured meshes [6] is used for the time integration. Accuracy of the TAS-Code has been validated for various flow problems [3, 7].

In aerodynamic shape optimizations, non-linearity of the objective functions must be taken into consideration. Therefore, an in-house solver of real-coded GA is adopted. It is a population-based optimization method simulating the evolutionary process of creatures, in which the population evolves over generations to minimize/maximize the objective functions by the operations of selection, crossover and mutation [8]. It is well-known that GA requires large computational cost due to population-based search, particularly coupled with expensive CFD solvers. Therefore, the Kriging model [9] is adopted to build an approximation model of the objective functions to reduce the computational burden. Optimal solutions are searched over the approximation model by Adaptive Range Multiobjective GA [10]. The flowchart of the current optimization system is shown in Fig. 2. The first sampling points are determined by the Latin Hypercube sampling method [11] to distribute the points in equi-distance space. Kriging approximation model is then constructed based on the sample data, and the model is used for the objective function evaluation in the optimization process. In this study, the objective function (L/D) was transformed to the corresponding Expected Improvement (EI) to find the global optimal point robustly. Finally, ANOVA is performed to identify the effect of each design variable and its interaction to L/D [12], which specifies the important and contributed design variables to L/D.

**Fig.2 Flowchart of the current optimization system**

III. Over-the-Wing-Nacelle configuration

In this section, preliminary analyses are conducted to validate the aerodynamic feasibilities of Over-the-Wing-Nacelle (OWN) configurations at cruise condition. The configuration is based on DLR-F6 composed of fuselage, wing, nacelle and pylon used in the Third AIAA Drag Prediction Workshop [13]. The original design Mach number of DLR-F6 configuration is 0.75. In this research, the flow condition was set to Mach number of 0.70 to focus on mid-sized, short-range aircraft for Japanese domestic use. The lift coefficient $C_L$ was kept 0.57 by adjusting the angle of attack. This analysis is performed on wing-fuselage configuration with/without disjoint nacelles. The flow-throw nacelle is used because the validity of flow-through nacelle simulation was proved in [2].

Flows around three configurations were simulated by Euler solver for comparison. The results of pressure distributions and L/D of respective configurations are shown in Fig. 3. The wing-body configuration (a) achieved L/D of 33.8, but the OWN configuration whose nacelle installed at the 50% chord position (b) achieved much less
L/D of 18.8. When the engine nacelle is moved rearward at the 60% chord position, the configuration (c) achieved better L/D of 20.2 compared to the geometry (b). In this research, the following function was used for the detection of the shock region.

\[ f_{\text{shock}} = \left( \frac{\mathbf{u} \cdot \nabla P}{a |\nabla P|} \right) \]  

As shown in figures (b) and (c) by gray, the OWN configurations easily generate shock waves around nacelle pylons. These shock waves increase the drag and L/D is strongly related to the position of engine nacelle installed. Therefore, conducting the optimization of the nacelle position and the nacelle shape, aerodynamically feasible OWN configuration will be obtained.

Fig. 3 Three configurations wing body with/without Nacelle (continued)
IV. Nacelle position and shape optimization

In this section, the engine nacelle position and its shape are designed by GA optimizer to improve L/D by reducing the interference effect between a wing and a nacelle.

A. Geometry Definition

In section III, preliminary analyses revealed that L/D can be improved by modifying the interference effect between a wing and a nacelle for OWN configuration. In the present section, the nacelle position and shape are optimized, while the NASA SC(2)-0008 airfoil is selected for the pylon. Horizontal and vertical tails are not modeled as it does not affect the whole aerodynamic performance.

The nacelle position is defined by two design variables (p1, p2) representing front-rear and vertical movement. The lower surface of nacelle is defined by Bezier surface of four control points shown in Fig. 4. Bezier surface is controlled by the x, y, z coordinates of four control points, which correspond to 12 design variables (4×3=12variables).

On the other hand, the upper surface of nacelle is frozen to original DRL-F6 type. When a new lower surface is defined by Bezier surface of four control points, the upper surface of DLR-F6’s nacelle is combined with the designed lower surface. When new nacelle position and shape are generated, the intersection between a new nacelle and a pylon is automatically extracted. The new surface mesh is then generated based on the advancing front method [14] (Fig. 5). The tetrahedral volume mesh is finally generated using Delaunay approach [15]. Qualitative volume mesh for a new wing-fuselage-pylon-nacelle configuration is always generated with the number of nodes around 1.3 million.
B. Objectives and Constraint

In this optimization, the following optimization problem is executed to maximize L/D. The flow condition is set to Mach number of 0.70, while $C_L$ is kept 0.57 by adjusting the angle of attack. The nacelle position is defined by two design variables representing front-rear and vertical movement. In addition, the lower surface of nacelle is defined by 12 design variables. Therefore, there are 14 design variables in total.

**Objective:** Maximization of L/D  
**Constraint:** constant $C_L = 0.57$  
**Number of design variables:** 14
C. Result and Discussion

The first Kriging model was constructed using 90 sample points of the Latin Hypercube sampling. The cross validation of this model is shown in Fig. 6, and it indicates that a considerably accurate approximation model was constructed. The final Kriging model was constructed with 125 sample points in total after 10 updates.

The optimal design OPTIMAL1 was obtained after the optimization and L/D of 27.3 was achieved at the angle of attack of 1.25 degrees. In order to compare the effect of nacelle lower surface with original configuration, GEOMETRY1 is constructed based on DLR-F6. The nacelle shape of GEOMETRY1 is the same as original, but the nacelle position is installed at the same position of the optimal design OPTIMAL1. The nacelle position parameters of the OPTIMAL1 are described in Table 2.

The surface pressures of GEOMETRY1 and OPTIMAL1 are shown in Fig. 7. OPTIMAL1 achieved L/D of 27.3, while GEOMETRY1 achieved lower L/D of 25.0. According to the result, optimizing the lower surface of nacelle is contributed to reduce the shock wave. Cut plane of the OWN configuration at 32% and 37% semi-span location is shown in Fig. 8. In Figs. 9 and 10, Mach number distributions of GEOMETRY1 and OPTIMAL1 at 32% and 37% semi-span location are shown. It indicates that shock wave is generated on GEOMETRY1, but it is not generated on OPTIMAL1. We conclude that the shock wave become weaker because the flow channel between the wing and the nacelle was optimized to prevent the interference effect.

In order to identify the effect of each design variable on L/D, an ANOVA was performed and the results are summarized in Fig. 11. According to the results, X/c and Z/h are important design variables, which are directly related to nacelle position. In Fig. 12, L/D distributions with X/c and Z/h are plotted. These plots mean when distance from a nacelle to a wing is farther, L/D tends to increase significantly by suppressing aerodynamic interference effect between a nacelle and a wing. However, it is structurally unfavorable when a nacelle is installed at the aft of the wing or at the higher position. In addition, it is also unfavorable that the nacelle is located at high for the ease maintenance. Therefore, it is needed to find the way to lower X/c and Z/h for considering a realistic aircraft.

![Fig. 6 Cross validation result of Kriging model created by first sample points](image)

### Table 2 Nacelle position parameter of the OPTIMAL1

| Nacelle position | Value  |
|------------------|--------|
| X/c              | 0.79   |
| Z/h              | 0.75   |

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Fig. 7 Comparison of nacelle geometry and flow field
Upper: pressure distribution of GEOMETRY1 (L/D=25.0)
Lower: pressure distribution of OPTIMAL1 (L/D=27.3)

Fig. 8 Cut plane at 32% and 37% semi-span location
Fig. 9 Mach number distribution of GEOMETRY1
(Left: 32% semi span, Right: 37% semi span)

Fig. 10 Mach number distribution of OPTIMAL1
(Left: 32% semi span, Right: 37% semi span)

Fig. 11 ANOVA results

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V. Wing and nacelle shape optimization

In Section IV, an optimization of the nacelle position and its shape was conducted. However, the optimized nacelle was located away from a wing to reduce the aerodynamic interference between the nacelle and the wing. In addition, it led that nacelle had to be placed away from a wing to improve L/D for OWN configurations.

The objective of this section is to investigate the feasibility of aerodynamically-efficient OWN configuration with consideration of structural and maintenance necessities. For this purpose, two other objective functions of geometric parameters of a nacelle are introduced in addition to maximize L/D. Here, nacelle position parameters are also set to be optimized: minimization of X/c and Z/h. These constraints enable an optimizer to find high L/D configuration at a forward and downward nacelle position for realistic configuration. However, further optimization of the flow channel between a nacelle and a wing is needed to improve L/D drastically – favorably higher than conventional Under-the-Wing-Nacelle geometry. Therefore, the wing shape is also modified by GA optimizer to improve L/D in addition to the engine nacelle position and its shape.

A. Geometry Definition

The 3-D wing shape is defined by the following 30 design variables to control the airfoil shapes. The root, tip and kink sectional airfoils are defined by nine design variables each according to the PARSEC definition [16, 17] as shown in Fig.13. The remaining sectional airfoils are linearly interpolated. In such parameterization, the complex shape of each airfoil can be represented by a relatively small number of meaningful engineering parameters such as the crest of the upper surface’s Z coordinate (Z_up), the crest of the lower surface’s Z coordinate (Z_lo) and the leading edge radius (r_LE). This engineering parameterization is useful for designers to analyze optimized data directly. In addition, the wash-out is defined by two design variables at tip and kink position (T_kink, T_tip). Further, the incidence angle (θ) is defined at root position. In this optimization, the planform of the wing is frozen to original DLR-F6 type. The planform with the design section is shown in Fig. 14.

The engine nacelle position and its shape are optimized under the same design variables of Section IV. The ranges of design parameters are shown in Table 3. Therefore, there are 44 design variables in total.
Table 3 Range of design parameters

| Parameter | Min  | Max  |
|-----------|------|------|
| $r_e$     | 0.005| 0.06 |
| $Z_{Te}$  | -0.015| 0.015|
| $\alpha_{Te}$ | -8deg. | -3deg. |
| $X_{up}$  | 0.35 | 0.50 |
| $Z_{up}$  | 0.06 | 0.13 |
| $Z_{xup}$ | -1.0 | -0.2 |
| $X_{lo}$  | 0.35 | 0.5 |
| $Z_{lo}$  | -0.13 | -0.06 |
| $Z_{xlo}$ | 0.1 | 1.0 |
| Wash-out_tip | -4deg. | 4deg. |
| Wash-out_kink | -4deg. | 4deg. |
| Incidence angle | 0deg | 8deg |

B. Objectives and Constraint

In this optimization, the main objectives are to maximize $L/D$. As mentioned above, $X/c$ and $Z/h$ are also employed for the sub-objectives to explore the configuration of high $L/D$, low $X/c$ and low $Z/h$. The flow condition and constraints are set as the same of Section IV.

**Objective1**: Maximization of $L/D$

**Objective2**: Minimization of $X/c$

**Objective3**: Minimization of $Z/h$

**Constraint**: constant $C_L = 0.57$

**Number of design variables**: 44 (Nacelle shape and its position: 14, wing shape: 30)
C. Result and Discussion

The first Kriging model was constructed using 79 sample points of the Latin Hypercube sampling. The cross validation of this model is shown in Fig. 15, and it indicates that a reasonable approximation model was constructed. The final Kriging model was constructed with 169 sample points in total after 12 updates. Several non-dominated solutions on the approximate model were chosen at each update to increase accuracy of the approximation.

Figure 16 shows objective-function space, which also means the relation between L/D and nacelle position parameters. Due to the introduction of sub-objectives (X/c and Z/h), optimizer found higher L/D configurations at the nacelle position of forward and downward compared to results in Section IV.

One configuration having low X/c and Z/h parameters is chosen from non-dominated solutions (OPTIMAL2), whose nacelle position parameters are described in Table 4. The wing geometrical parameters of the OPTIMAL2 are described in Table 5. This achieved L/D of 33.6 at adjusted angle of attack of 5.71 degrees.

The surface pressure of the OPTIMAL1 and the OPTIMAL2 are shown in Fig.17. From these figures, the shock wave of the OPTIMAL2 is slightly stronger than that of the OPTIMAL1 because the nacelle position of the OPTIMAL2 is forward and downward compared to the OPTIMAL1. However, OPTIMAL2 achieved higher L/D than that of OPTIMAL1. It is because the wing shape was optimized at Mach number of 0.70 to explore the suitable configuration for OWN.

The drag coefficient of the OPTIMAL1 and the OPTIMAL2 is shown in Fig. 20. It indicates that optimization of the wing shape is contributed to reduce the drag of inboard and outboard. However, the fuselage drag of the OPTIMAL2 is higher than the OPTIMAL1. It is because the OPTIMAL2 requires higher A.o.A (5.71 degree) to obtain the same lift much the OPTIMAL1 (1.25 degree).

Finally, in order to identify the effect of each design variable on L/D, an ANOVA was performed and the results are summarized in Fig. 21. As a result, Z_up, Z_lo, and r_le at the kink are important design variables. This investigation is quite reasonable because Z_up and Z_lo (thickness) control the camber related to lift and r_le (leading-edge radius) affects the flow acceleration. Therefore, it indicates that ideal wing shapes need to have the large camber to obtain the lift and the small leading-edge radius to avoid the flow acceleration. In Figs. 22 and 23, L/D distributions with Z_up, Z_lo, r_le, and washout at the kink are plotted.

Fig. 15 Cross validation result of Kriging model created by first sample points
Table 4 Nacelle position parameter of the \textit{OPTIMAL1}, \textit{OPTIMAL2}

|                | \textit{OPTIMAL1} | \textit{OPTIMAL2} |
|----------------|-------------------|-------------------|
| Nacelle position X/c | 0.79              | 0.73              |
| Nacelle position Z/h | 0.75              | 0.48              |
| L/D             | 27.3              | 34.5              |

Table 5 Wing geometry of the \textit{OPTIMAL2}

|                        |                  |
|------------------------|------------------|
| Thickness\_Root        | 17.8\%           |
| Thickness\_Kink        | 16.1\%           |
| Thickness\_Tip         | 16.5\%           |
| Washout\_Kink          | -3.0\text{deg}.  |
| Washout\_Tip           | -2.4\text{deg}.  |
| Incidence angle\_Root  | 0.1\text{deg}.   |

Fig. 16 L/D distribution (Left: X/c, Right: Z/h)

Fig. 17 Comparison of nacelle geometry and flow field
Upper: pressure distribution of \textit{OPTIMAL1} (L/D=27.3)
Lower: pressure distribution of \textit{OPTIMAL2} (L/D=34.5)
Fig. 18 Mach number distribution of OPTIMAL1
(Left: 32% semi span, Right: 37% semi span)

Fig. 19 Mach number distribution of OPTIMAL2
(Left: 32% semi span, Right: 37% semi span)

Fig. 20 Drag coefficient
(Left: OPTIMAL1, Right: OPTIMAL2)

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VI. Pylon shape optimization

In section V, it appeared that the shock wave of the OMPIMAL2 was slightly stronger than that of the OPTIMAL1 because the nacelle position of the OPTIMAL2 was forward and downward compared to the OPTIMAL1. However, this shock wave leads to an increase of the wave drag. Therefore, the pylon shape optimization is conducted for the further reduction of interference effect between a wing and a nacelle. In this section, the nacelle position, nacelle shape and wing shape are frozen to the OPTIMAL2 configuration, and only the pylon is designed.

A. Geometry Definition

The wing thickness of the pylon is defined by Bezier curve of four control points shown in Fig. 24. There are seven design variables to control the wing thickness of the pylon. By using this geometrical definition, symmetrical airfoil of the pylon is represented. In addition, the camber is defined by Bezier curve of five control points shown in
Fig. 25. The camber is controlled by the x, y coordinates of five control points, which correspond to eight design variables ($1 + 3 \times 2 + 1 = 8$ variables). Finally, new pylon shape is generated by combining the wing thickness of the pylon with the camber. Therefore, 15 design variables are used in total.

**B. Objectives and Constraint**

In this optimization, the objective function is to maximize L/D. The flow condition is set to Mach number of 0.70, while $C_L$ is kept 0.57 by adjusting the angle of attack. There are 15 design variables in total.

- **Objective**: Maximization of L/D
- **Constraint**: constant $C_L = 0.57$
- **Number of design variables**: 15 (The thickness of pylon: 7, the camber of pylon: 8)

**C. Result and Discussion**

The first Kriging model was constructed using 41 sample points of the Latin Hypercube sampling. The cross validation of this model is shown in Fig. 26, and it indicates that a considerably accurate approximation model was constructed. The final Kriging model was constructed with 79 sample points in total after five updates.

The optimal design OPTIMAL3 was obtained after the optimization and L/D of 35.5 was achieved at the angle of attack of 5.85 degrees. The results of OPTIMAL2 and 3 are described in Table 6, and OPTIMAL3 achieved 5 counts drag reduction. Cut plane of the OWN configuration at 32% and 37% semi-span location is shown in Fig. 27.

In Fig. 28, pressure distributions of OPTIMAL2 and OPTIMAL3 at 32 % and 37% semi span are shown. According to the result, the OPTIMAL3 reduces the buffet near the trailing edge compared to the OPTIMAL2. The pylon shapes of OPTIMAL2 (NASA-SC(2)-0008) and OPTIMAL3 are shown in Fig. 29. From this figure, the leading edge radius of OPTIMAL3’s pylon is smaller than that of OPTIMAL2. This enables to avoid flow acceleration...
between wing and nacelle. The drag coefficient of the OPTIMAL2 and the OPTIMAL3 is shown in Fig. 30. It indicates that optimization of the pylon shape is contributed to reduce the drag of inboard and outboard.

In this optimization, nacelle position, nacelle shape and wing shape were not optimized to reduce design variables. Therefore, further optimization to integrate all components such as nacelle position, nacelle shape and wing shape will enhance the aerodynamic performance of OWN configuration.

![Fig. 26 Cross validation result of Kriging model created by first sample points](image)

| Table 6 L/D of OPTIMAL2 and OPTIMAL3 |
|--------------------------------------|
|                                       | OPTIMAL2 | OPTIMAL3 |
| Pylon thickness                       | 8.0%     | 9.0%     |
| L/D                                  | 34.5     | 35.5     |

![Fig. 27 Cut plane at 32% and 37% semi-span location](image)
D. Comparison with DLR-F6 configuration (conventional UWN configuration)

In this part, the feasibility of OWN configuration is discussed by comparing with DLR-F6 configuration (UWN configuration). The original design Mach number of DLR-F6 is 0.75. However, the Mach number is set to 0.70 to focus on mid-sized, short-range aircraft in this research. Though it is not fully fair comparisons, the cruise performances of DLR-F6 and optimized OWN at Mach number of 0.70 are compared in this section to investigate the aerodynamic feasibility of OWN configuration. The performances are summarized in Table 7. From this result, it
demonstrates that optimized OWN configuration is able to achieve higher L/D than that of DLR-F6 configuration. This proves that OWN configuration has a potential to achieve high L/D comparable to conventional UWN by applying optimization techniques. When OWN configuration is realized, it is expected that the length of a landing gear can be much shortened compared to that of UWN configuration. This enables to reduce the total weight of the aircraft, which leads the increase of aerodynamic performance. In addition as mentioned above, OWN configuration has an advantage of a shielding effect of the noise propagation toward the ground caused by fan and jet noises. By conducting further optimization integrating all the components at various flight conditions, OWN configuration will be able to prove that it is a potential candidate to be a near-future aircraft.

| Table 7 Cruise performance of DLR-F6 and OWN |
|---------------------------------------------|
| L/D  | DLR-F6 | OWN |
|------|--------|-----|
| L/D  | 31.7   | 35.5|

VII. Conclusion

Aerodynamic optimization of OWN configuration was conducted by modifying nacelle position, nacelle shape, wing shape and pylon shape to investigate the usefulness of an OWN configuration. Firstly, the nacelle position and its shape were optimized to maximize the L/D. As a result of the optimization, the optimal shape achieved L/D of 27.3. The shock wave of the optimal geometry is weaker than original DLR-F6-based configuration, which avoids unfavorable aerodynamic interference between a nacelle and a wing. According to ANOVA results, X/c and Z/h are important design variables. However, it appears the nacelle has to be placed away from the wing to reduce the aerodynamic interference between a nacelle and a wing for high L/D.

Secondly, the wing shape was also optimized in addition to nacelle shape and position. The objectives of the optimization were set to maximize L/D and to minimize X/c and Z/h for a realistic aircraft with a structural and maintenance point of view. As a result of the optimization, we obtained a configuration achieving L/D of 34.5, and the nacelle position was more forward and lower than the optimal shape of section IV. It reveals that the nacelle position is highly related to aerodynamic performance of OWN configuration, however, reasonable L/D can be obtained by the modification of nacelle and wing shape even when the nacelle is close to a wing.

Finally, the pylon shape of the above optimal configuration was further optimized to reduce the interference effect between a wing and a nacelle. As a result of the optimization, the buffet near the trailing edge was weakened compared with original pylon shape. This enabled to achieve higher L/D of 35.5 corresponding to 5 drag counts reduction from the second optimization. Further integrated optimization of nacelle position, nacelle shape and wing shape will be contributed to improve the aerodynamic performance of OWN configuration drastically. Through the present aerodynamic optimizations of OWN configuration, it is concluded that an aerodynamically-efficient OWN configuration comparable to conventional UWN will be realized feasible with further optimization under the various flight conditions.

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