THREE-SURFACE AIRCRAFT - A CONCEPT FOR FUTURE LARGE AIRCRAFT

G. Wichmann, D. Strohmeyer, Th. Streit
German Aerospace Center, DLR
Lilienthalplatz 7, 38108 Braunschweig, Germany

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Abstract

In this paper the activities of the Institute of Design Aerodynamics within the DLR project "Dreiflächen-Flugzeug (3FF)" - Three-Surface Aircraft, TSA - concerning the investigation of three-surface aircraft configurations are presented. Results of aircraft predesign calculations of the retrofitted wind-tunnel model DLR-F11 show higher performances for the optimised TSA configuration compared to the conventional design. However, the performance increase is coupled with a loss of static stability. Under the boundary condition of equal static stability, the same performance gain is achieved with a conventional design. The possible performance potential of TSA configurations can only be realised if the concept of a "free-floating canard", which does not influence the static stability, is taken into account. Corresponding transonic canard designs demonstrate the aerodynamic feasibility of the canard concept for transport aircraft configurations at high cruise Mach numbers for a backward swept canard at a low aft position and a forward swept canard at a low front position.

1 Introduction

Analyses of the International Air Traffic Association (IATA) predict an annual increase of the world-wide air traffic between 5% and 7% for the next decades. Based on these predictions the large aircraft companies and national aeronautical research institutes work on alternative concepts such as the Megaliner (A3XX), which go beyond the conventional stretching of the existing wide bodies. Conventional aircraft configurations are defined by a fuselage for payload, a high aspect ratio wing with transonic performances, stabiliser and control surfaces and under wing mounted engines. Improvements only can be reached by size effects or by employing more sophisticated technologies, which, without proper guidance, is counterproductive to competitive and economic targets or even operational requirements. In a long run only new unconventional civil transport aircraft configurations show major improvements and promise a considerable progress in productivity even and in particular under future economic and environmental demands. The key drivers of aircraft efficiency are weight and aerodynamics. By means of their configurational features unconventional configurations can offer a much greater potential to improve these characteristics than might be achieved by further improving conventional aircraft configurations with the same technology level. Studies carried out during the last decades have shown a large improvement potential which can be exploited if one is ready to accept unconventional solutions.

The three-surface aircraft with an additional third wing in the forebody region of the aircraft, the "canard", represents such a concept for future large transport aircraft, **Fig. 1**. The objective of the canard in addition to the TSA's horizontal tailplane (HTP) is to achieve additional lift in the forebody region and therefore to

- *reduce negative lift required from the HTP to trim the aircraft at cruise and high lift conditions reducing the induced drag of the total configuration,*
- *allow a larger aircraft with higher maximum take-off weight at fixed wing size - or - allow a smaller wing at fixed aircraft size and take-off weight,*

- *improve rotation capability at take-off.*

An installation of a canard has a significant influence on the overall design of the configuration. The potential of the TSA concept depends strongly on the flight mechanics concept. That is, the benefits of using a canard are most promising for a neutrally stable or even unstable aircraft. Stability augmentation could then be performed by automatic scheduling of the canard to keep it at a fixed local incidence that is needed for trim. However, by the canard installation also additional problems will occur, e.g. diminishing of fuselage's accessibility, or introduction of new aerodynamic interference effects, like canard downwash effects on the wing, particularly at yawing conditions.

In order to investigate the influence of the canard on the overall performance of the aircraft and to contribute in solving fundamental problems combined with the canard installation, DLR started a project "Three-Surface Aircraft".

In this paper the contribution of the Institute of Design Aerodynamics in the project is considered. After a short description of the project, a basic field of investigation, the further development and application of the predesign code PrADO for the prediction of the overall performance of three-surface configurations in comparison to conventional aircraft designs is presented, including results of preliminary three-surface aircraft designs. Additionally some characteristic features of the transonic aerodynamic canard design in the complex front fuselage flow of a three-surface configuration will be shown and first designs presented.

2 The DLR Project "Three-Surface Aircraft"

Within the DLR project "Three-Surface Aircraft", running 4 years from 1977 to 2000, basic questions concerning the application of canard wings for future and today's transport aircraft are investigated. All basic disciplines like aerodynamics, flight mechanics, aeroelastics and structure mechanics are involved in several working packages including predesign studies for the evaluation of the complete aircraft system.

The main objectives of the project are:

- *general: determination of the performance potential of a three-surface aircraft versus conventional configurations,*
- *aerodynamics: transonic canard design, determination of interference effects between canard, main wing and tailplane,*
- *flight mechanics: clarification of the longitudinal and lateral stability of a three-surface configuration, solution of the problem of reduced longitudinal stability,*
- *aeroelasticity: investigation of the influence of the flexible fuselage and the canard on the oscillation behaviour of the three-surface aircraft, detection of new flutter forms due to the presence of the canard,*
- *predesign: design/optimisation of a three-surface configuration, analysis concerning effectivity and economy and final evaluation of the complete aircraft system.*

The research methods reach from preliminary aircraft design tools over numerical flow simulation and wind-tunnel experiments up to flight-simulation tests with the DLR experimental aircraft ATTAS.

A wind-tunnel half model with the name DLR-F11 has been planned and constructed at DLR, within a separate investment, for KKK (Cryogenic Wind Tunnel Cologne) and ETW (European Transonic Wind Tunnel) cryogenic investigations in close co-operation with DaimlerChrysler Aerospace. The wind-tunnel tests will be performed for clean and high lift configurations with and without canard covering the complete Reynolds number regime up to the high Reynolds numbers of ETW. A sketch of the model also showing the basic equipment for high lift configuration is presented in Fig. 2. The geometry consists of a scaled A340-200 fuselage with fairing and a transonic wing that has been designed based on the variable camber concept (VC concept). For smaller total lift coefficients the wing works at high cruise Mach numbers in clean configuration, for higher lift coefficients additional flap deflections are necessary to yield reasonable pressure distributions without shock-induced separation. The model will be equipped by a canard wing at the position resulting from predesign optimisation runs completed by a scaled A340 horizontal tailplane in order to investigate the three-surface configuration. Due to the fact that the model is designed for the A3XX cruise Mach number M=0.85 its basic configuration without canard was selected for first wall correction measurements in ETW. Thus the tests will represent an essential contribution to the installation of the half model technique in ETW.

3 Preliminary Aircraft Design

The task of the preliminary aircraft design within the framework of the project is twofold: on the one hand the basic geometry of an optimised canard for the DLR-F11 wind-tunnel model had to be defined, on the other hand, the performance of a three-surface aircraft had to be analysed and evaluated in comparison with a conventional aircraft design.

3.1. Design Code and Boundary Conditions

The integrated aircraft design and optimisation studies are based on the design code PrADO, **Fig. 3**. A detailed description of the design procedure and the implemented extensions for TSA (panel code, surface grid generator and transonic data base for a suitable description of the aerodynamics, trim routine for TSA under consideration of a trimtank in the HTP) is given in [1,2].

According to the fuselage size and the geometrical proportions of the DLR-F11 wind-tunnel model, the configuration was designed for an A340-200 transport mission: 262 passengers without additional cargo and 13800 km range. Along the cruise segment an idealised mission with constant lift coefficient, Mach number and variable altitude was prescribed to simulate a flight with almost constant aerodynamic characteristics. The mission was simulated for different lift coefficients (0.35, 0.40, ..., 0.55), using a parabolic interpolation to determine the lift coefficient for optimum L/D.

A further simplification was the assumption of fixed design weights - except the weight of the canard (and the horizontal tailplane, when sized) - modelling the retrofit of an existing aircraft with a canard.

The integration of a canard in the nose region of the aircraft reduces the static stability and influences the controllability of the aircraft. For this reason, static stability (a static margin of at least 10 % of the reference chord length) and controllability (a maximum trim angle of ±10° for the canard and ±15° for the horizontal tailplane) as well as the location of the main landing gear (to guarantee a minimum load of 5% of the maximum take-off weight on the nose landing gear during taxi on the runway) are checked at the end of the design process for each configuration.

For the optimisation of the 30°-swept canard four basic geometry parameters were chosen as optimisation variables and varied in a reasonable range: span ($9m \le b_C \le 18m$), aspect ratio ($3 \le A_C \le 8$), taper ratio ($0.3 \le \lambda_C \le 0.8$) and twist ($-6° \le \varepsilon_C \le 6°$), assuming a linear twist distribution. Further optimisation variables were the canard x-position of the swept back canard ($10m \le x_C \le 13m$) and the cruise Mach number ($0.82 \le M \le 0.87$). According to the aim of the study and following Bréguet's range equation, the product of aerodynamic efficiency and cruise Mach number L/D * M was chosen as objective function.

3.2 Design and Optimisation Procedure

The preliminary aircraft design study falls into two parts. In the first part, the retrofit of the geometrically fixed DLR-F11 configuration with a canard was analysed. It is called in the following the retrofit case. The best configurations of this analysis - forward swept and swept back canard - were taken as the basis for the transonic aerodynamic canard design (chapter 4).

In the second part a TSA design was simulated, taking into account the x-position of the wing and the size of the HTP: the x-position of the wing was introduced as additional optimisation variable and the HTP was re-sized in order to keep the tailplane volume of the DLR-F11 basic design constant, called in the following the design case. Since also the canard provides a contribution to the tailplane volume, the size of the HTP is reduced in this case.

Based on previous sensitivity analyses of the DLR-F11 retrofit on the preliminary aircraft design level [2] and first transonic aerodynamic canard design studies (chapter 4.1) the canard optimisation was limited to two cases: a forward swept canard at a fixed x-position close to the body nose (x_C=2.65m) and a swept back canard downstream the divergent body nose with variable x-position, both in a low-wing arrangement (z_C=-1.55m).

For the canard optimisation with PrADO a robust gradient method was applied [1]. Due to the high computational effort of optimisation calculations the following optimisation procedure was chosen:

1. three optimisation calculations with different startpoint but same size of the start step, stopped at the end of the third optimisation stage [1],
2. new simulation starting from the current optimum with a start-step size reduced by a factor of four, stopped again at the end of the third optimisation stage,
3. one-dimensional parameter studies from the new optimum for each optimisation variable to verify the (at least local) optimum.

3.3 Optimisation Results

The optimisation history of the four TSA designs - forward swept canard/swept back canard, retrofit/design - are illustrated exemplarily in **Fig. 4** for the aspect ratio, cruise Mach number and the objective function of the forward swept retrofit case. Final one-dimensional parameter studies lead to a further increase of the objective function from 18.02 up to 18.04. The geometry of the corresponding configuration is shown in **Fig. 5** the relevant design parameters are given in **Tab. 1**. This result for the forward swept retrofit optimum is in a good agreement with the findings of the previous sensitivity studies [2]: it is characterised by the maximum aspect ratio (low induced drag), a small taper ratio, close to the lower limit (low friction drag) and a combination of cruise Mach number and lift coefficient which guarantees a maximum use of the transonic performance potential (0.2 counts wave drag). Increasing the Mach number and/or the lift coefficient results in a significantly higher wave drag. Due to the strong increase of the wave-drag gradient for this flight conditions, the Mach-number and/or lift gain is overcompensated and the objective function reduced.

With respect to the canard span, the optimum is achieved for a medium span of 10.95m. A higher wing span provides additional friction drag which overcompensates the L/D gain based on the improved induced drag and the positive effect of a higher flight Mach number due to the reduced lift contribution of the wing. The opposite is true for a reduction of the optimum canard span.

A comparison between the forward swept TSA configuration and the baseline design without canard, Tab. 2, shows that the positive effects of the canard - less negative lift of the HTP for trimming, smaller lift contribution of the wing, higher cruise Mach number - allow an increase of the objective function from 17.97 up to 18.04, in spite of the additional friction drag. However, it has to be noted that also the static stability of the TSA configuration with a static margin of 27.9% is significantly smaller compared with the baseline design without canard.

The second retrofit optimisation for a swept back canard leads to a configuration with identical aspect ratio, higher span and almost the same taper ratio and twist (note that the negative sign indicates a higher angle of attack at the wing tip). The larger canard provides more lift, resulting in a higher total lift coefficient at almost the same cruise Mach number and wave drag. In spite of the 1.3 counts higher friction drag, the induced drag is improved (related to CA2/• /AW) and provides a higher L/D. The result is a further increase of the objective function up to 18.15, but obtained for a less stable configuration.

A further improvement of the L/D and the objective function can be realised if the boundary condition of a fixed tailplane volume is taken into account and the wing position is added to the optimisation variables (design case). The geometry of the corresponding optimisation results is illustrated in Fig. 5 and the relevant design variables are compared in Tab. 1. For both configurations, forward swept and swept back canard, the best design shows a higher lift coefficient and a slightly reduced cruise Mach number compared to the retrofit case. The combination of reduced friction drag, based on the smaller size of the HTP and the improved induced drag leads to a significantly higher L/D and an increase of the objective function. In addition, the position of the wing is shifted closer to the body nose, which leads to a further reduction of the static margin down to 10% and reduces the necessary trim forces.

An interesting aspect of the optimisation result is, that, in spite of the smaller HTP size, the optimum canard sizes differ only little from the sizes obtained in the retrofit case. This effect is based on the dominating influence of the induced drag, with an optimum at almost the same canard size.

Another aspect of interest is the high taper ratio of the forward swept canard of 0.8. Despite the higher friction drag compared to smaller taper ratios, the better induced drag of this canard shape provides a higher L/D. In addition, the influence of the taper ratio on the L/D in this particular case is only small - a reduction down to 0.3 results in a L/D decrease of only 0.004.

For an objective comparison between conventional design and TSA configuration concerning the performance potential, the baseline configuration without canard was optimised with respect to the Mach number and the position of the centre of gravity. For this purpose, the centre of gravity was (hypothetically) considered as a free design variable.

The result of this optimisation, summarised in Tab. 2, shows a slightly smaller L/D compared with the optimum TSA design, obtained at the same static margin of 10% and a higher cruise Mach number, which leads to a slightly higher objective function of 18.409. Opposite to the TSA designs, the HTP provides positive lift and reduces the lift contribution of the wing. This mechanism increases the induced drag but allows the higher cruise Mach number without increasing the wave drag.

In a final step an optimisation of the conventional design with respect to cruise Mach number and wing x-position was performed under the boundary condition of a fixed tailplane volume. The aim of this analysis was to determine to what extent a reduction of the static margin can be realised with rather conventional design modifications.

Table 2 shows that the optimum design is achieved for a cruise Mach number of 0.8365 and a wing position of 18.58m, leading only to a reduction of the static margin down to 38.4%. A further shift of the wing position closer to the nose cannot be realised due to the landing-gear restrictions (chapter 3.1). These final optimisation calculations show, that the same positive effect of a canard integration can be achieved with a conventional design if the static margin is reduced to the same extent. For this purpose further design modifications, such as additional trim tanks in the vertical tailplane or the cargo compartment, have to be taken into account, which go beyond a conventional shift of the wing position.

However, the TSA performance potential can be further exploited if a so called "free-floating canard" is used, which leads to a TSA with the same static stability as the conventional design.

4 Transonic Aerodynamic Canard Design

The forebody flow of a transport aircraft configuration is dominated by complex three dimensional characteristics: more or less high flow accelerations from the nose to the beginning of the cylindrical fuselage part, fuselage induced up and downwash effects in the surrounding flow field which strongly depend on the special front fuselage shape and free stream conditions. The aerodynamic quality of a canard installed here can be completely changed by these fuselage influences compared to an undisturbed canard flow. This situation is even more critical at transonic speeds due to the risk of shock appearance. Thus an aerodynamic canard design with acceptable performances is difficult in this region and must be performed carefully [3].

4.1 General Installation Aspects

Former studies demonstrated that detailed aerodynamic designs of canards with reasonable pressure distributions are possible including the relevant interference effects with the wing and fuselage. This has been proved for both, a canard placed at low forward as well as at rear high fuselage positions [4].

Results of basic investigations using the DLR-F11 fuselage geometry are presented in the following. The Euler analysis of the separate fuselage at cruise condition M=0.85 and $\alpha=1.6^{\circ}$ in **Fig. 6** shows a smooth surface flow without shocks or higher local Mach numbers indicating reasonable surface curvature distributions. The front fuselage region can be divided in three parts which essentially influence canards installed here. The first part can be interpreted as the stagnation region of the fuselage nose with lower velocities, followed by the region of accelerated flow representing the transition to the cylindrical fuselage part and finally the beginning of the cylindrical fuselage tube with stabilised flow of nearly free stream condition. An example in Fig. 7 indicates that a canard in low front position will be influenced by the fuselage-induced downwash in this region that only can be compensated by corresponding canard twist.

The influence of the streamwise variation of canard location in a low wing position on its transonic flow characteristics has been determined by systematic Euler analyses and is presented in the following. The situation for a swept back canard configuration is given in Fig. 8 and for a forward swept configuration in Fig. 9, respectively. For a constant lift coefficient at M=0.85 the upper surface iso-Mach and a selected section pressure distribution of the canard installed at the three above mentioned forebody locations (stagnation, acceleration and stabilised region) is shown.

In the case of the swept back configuration in Fig. 8 the aft canard location clearly results as the aerodynamically most profitable one. It shows the weakest shock most upstream. At the front as well as the mid canard location strong shocks at the canard trailing edge are generated due to the fuselage induced flow acceleration in these regions, additionally affected by the so-called "mid effect" of swept wings leading to a concentration of isobars in trailing edge direction. This effect is even amplified by the diverging fuselage nose.

The forward swept canard configuration shows a rather different situation (Fig. 9). While the mid and aft positioned canards show strong trailing edge shocks, due to the fuselage induced flow accelerations, leading to early flow separation, the pressure distribution of the front located canard with a shock near the leading edge is useable. This type of pressure distribution is dominated by the "mid effect" of swept wings, too. In opposite to the swept back case, it leads for forward swept wings to isobar concentrations in the leading edge direction.

Thus it can be summarised that the fuselage mid position (flow acceleration region before entering the cylindrical fuselage part) is not suitable for both, an installation of a swept back and a forward swept canard. It results that the forward swept canard configuration shows clear advantages in the fuselage forebody stagnation region and the swept back canard is more useful in the cylindrical fuselage part. Consequently these two possible solutions have been prepared for further predesign investigations (chapter 3.2).

4.2 DLR-F11 configuration design results

Based on the general investigations concerning the transonic features of the canard installation mentioned above as well as on the results of the predesign optimisation of the retrofitted DLR-F11 model, two canard designs for the transonic cruise condition M=0.85 and $c_L\approx0.3$ have been performed: A swept back canard in low aft position i.e. at the beginning of the cylindrical fuselage tube and a forward swept canard in low front position i.e. in the stagnation region of the diverging fuselage nose.

The swept back design is presented in **Fig. 10**. The upper surface isobars as well as the selected section pressure distribution plots show a reasonable pressure development with a moderate shock becoming stronger in spanwise direction. A shock-free design with the predesign prescribed c_L=0.293 and geometry is impossible since the local c_l reaches values up to c_l=0.58. The resulting additional wave drag related to the total aircraft configuration amounts to $\Delta c_D\approx1.7$ counts. The corresponding forward swept canard design is shown in **Fig. 11**. The figures show a shock-free flow. The calculated lift coefficient is c_L=0.283. There is no additional wave-drag due to the canard. For the off-design condition with

c_L=0.42 and M=0.85, the additional canard wave drag related to the total aircraft configuration only amounts to $\Delta c_D \approx 0.28$ counts. The comparison of these configurations shows that the forward swept canard design has a greater aerodynamic potential because of its better off-design performance, i.e. higher margins related to drag rise and buffet onset.

Following the installation of the forward swept canard as suggested, some additional remarks must be done. Of course the problems combined with pilot's visibility and accessibility of the fuselage remain to be solved. Structural and aeroelastic disadvantages like higher structural weights for forward swept wings can be solved by the application of new materials. On the other hand a forward swept canard turns out to be more suitable to fulfil the required trim conditions, especially if placed in front position.

5 Conclusions

In this paper the activities of the Institute of Design Aerodynamics within the DLR project "Dreiflächen-Flugzeug (3FF)" - Three-Surface Aircraft, TSA - concerning the investigation of three-surface aircraft configurations are presented. The main features of the project are described, followed by the consideration of a basic field of investigation, i.e. the further development and application of the predesign code PrADO for the prediction of the overall performance of three-surface configurations in comparison to conventional aircraft designs. In addition, some basic problems concerning the transonic aerodynamic canard design in the complex front fuselage flow of a three-surface configuration are discussed. The following results have been obtained:

- *Preliminary aircraft design*
  - *Integrated aircraft design studies on the basis of a transonic A340-type configuration indicate an increase of the aerodynamic performance potential up to 2.3% due to the integration of a canard.*
  - *A comparison between TSA and conventional design at the same minimum static stability - a static margin of 10% shows equivalent aerodynamic performance.*
  - *The performance potential of TSA versus conventional designs can only be realised if the control concept of a so-called "free-floating canard", which does not influence the static stability, is taken into account.*
- *Transonic aerodynamic canard design*
  - *Numerical studies demonstrate the aerodynamic feasibility of fuselage/canard configurations in transonic flow.*
  - *Parameter studies concerning the streamwise canard position result in two possible location: A front low position for a forward swept canard and an aft low position for a swept back canard.*
  - *The canard with a forward swept planform turns out to be more promising due to better off-design performance.*

The future aspects within the DLR project "Dreiflächen-Flugzeug (3FF)" are the continuation of work especially with detailed studies in the fields of aerodynamic interference, flight mechanics and aeroelastics of three-surface configurations. Important in this context are the experimental investigations covering the whole Reynolds number range in order to yield both, performance determination of three-surface aircraft and a database for the validation of numerical techniques.

References

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Figures

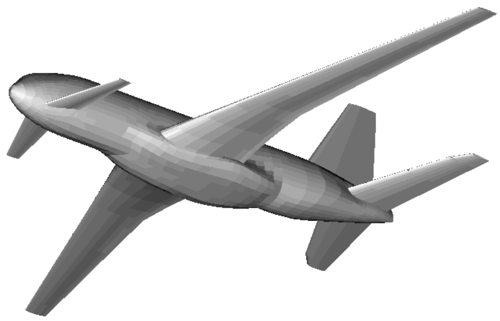


Fig. 1: Transport aircraft as a three-surface configuration.

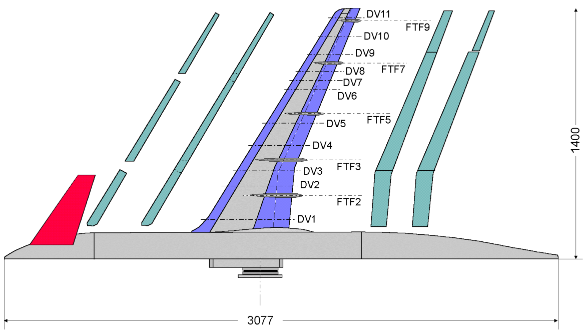


Fig. 2: Cryogenic half model DLR-F11 with high lift components.

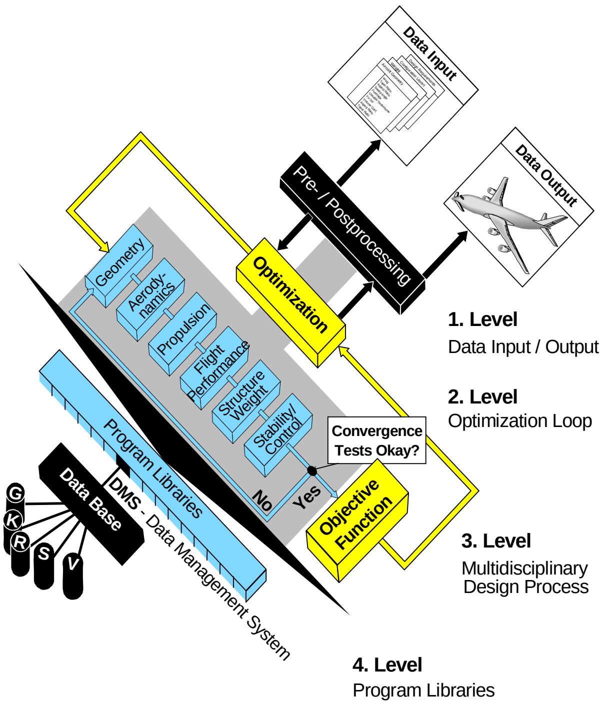


Fig. 3: Structure of the preliminary aircraft design code PrADO [1].

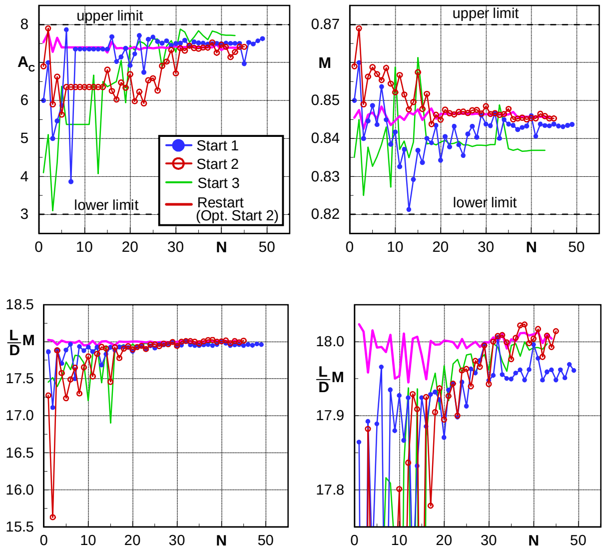
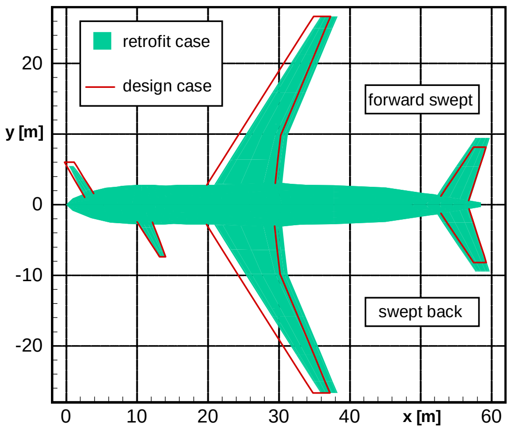


Fig. 4: Optimisation history for the TSA retrofit with forward swept canard (aspect ratio, cruise Mach number and objective function).



		forward swept canard		swept back canard	
		retrofit	design	retrofit	design
A_C	[-]	8.00	8.00	8.00	8.00
b_C	[m]	10.95	12.08	14.54	14.80
λ_C	[-]	0.33	0.80	0.31	0.30
ε_C	[°]	-4.28	-6.00	-4.14	-6.00
x_C	[m]	2.65	2.65	10.00	10.00
x_W	[m]	19.07	18.11	19.07	18.02
S_{HTP}	[m^2]	70.57	51.41	70.57	52.14
S_C	[m^2]	14.99	18.24	26.43	27.38

Fig. 5: Geometry of the optimised TSA configurations.

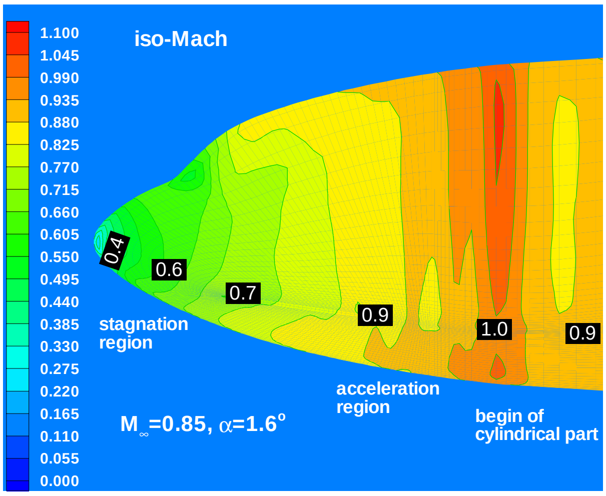


Fig. 6: Front fuselage flow of the DLR-F11 model.

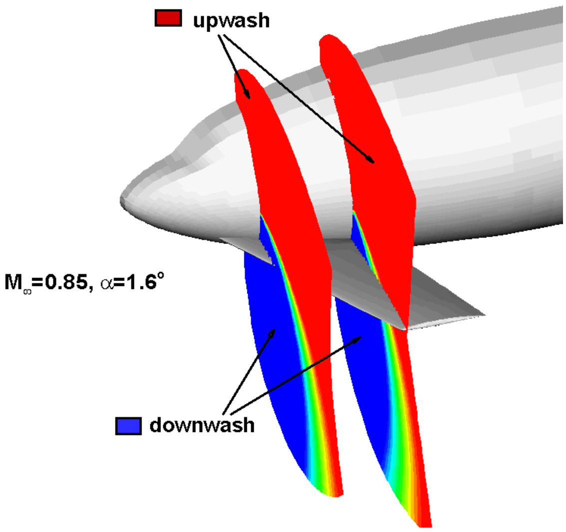


Fig. 7: Upwash and downwash of the isolated fuselage (canard included only for illustration purpose).

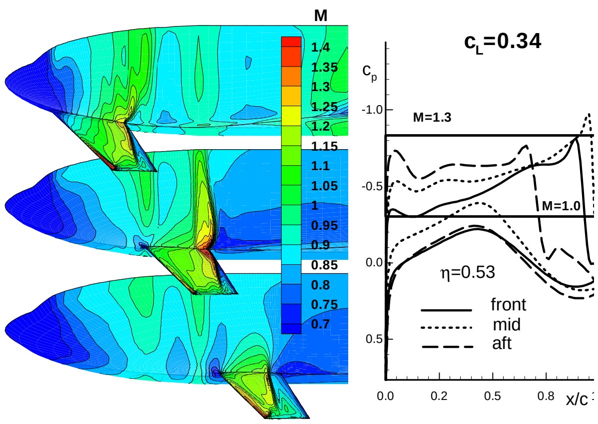


Fig. 8: Streamwise variation of the canard position for a swept back canard.

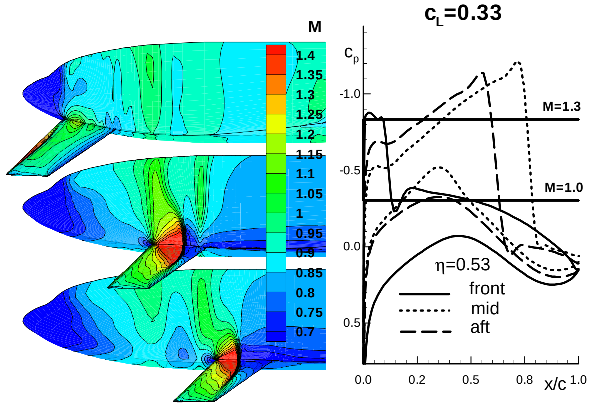


Fig. 9: Streamwise variation of the canard position for a forward swept canard.

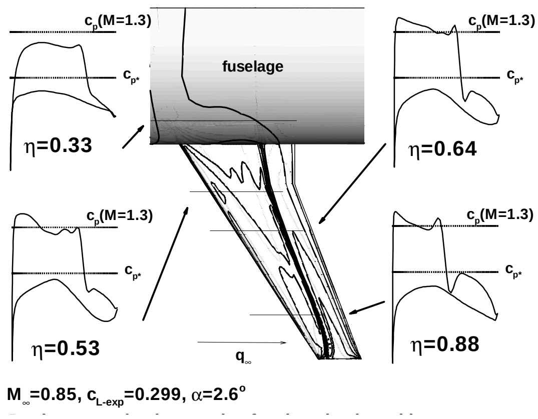


Fig. 10: Design of a swept back canard at aft fuselage position.

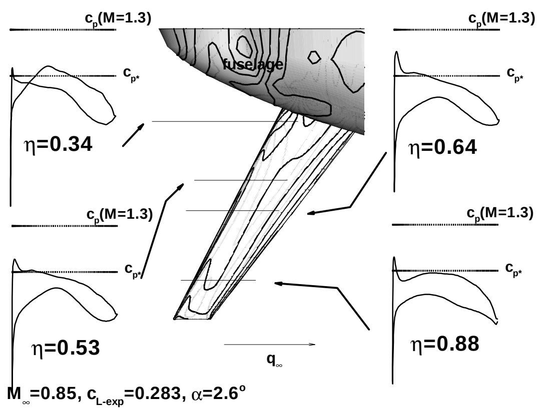


Fig. 11: Design of a forward swept canard at front fuselage position.

Tables

				forward swept canard		swept back canard	
				retrofit	design	retrofit	design
objective function (L/D*M)				18.039	18.313	18.150	18.388
cruise Mach number				0.8455	0.8403	0.8452	0.8411
aerodynamics:	lift:	canard		0.0145	0.0148	0.0256	0.0222
		wing		0.4279	0.4381	0.4248	0.4338
		htp		-0.0089	-0.0029	-0.0079	-0.0059
		fuselage		0.0623	0.0648	0.0681	0.0702
		total		0.4958	0.5148	0.5106	0.5203
	drag:	induced		0.00921	0.00972	0.00961	0.00985
		friction		0.01273	0.01262	0.01286	0.01265
		wave		0.00002	0.00002	0.00002	0.00003
		interference		0.00128	0.00126	0.00129	0.00127
		total		0.02324	0.02362	0.02378	0.02380
	L/D			21.34	21.79	21.47	21.86
stability:	x-pos. centre of gravity		[m]	27.54	26.92	27.52	26.77
	x-pos. neutral point		[m]	29.44	27.60	29.06	27.45
	static margin		[%]	27.9	10.0	22.6	10.0
weights:	canard		[t]	0.4	0.5	0.7	0.7
	operating empty		[t]	114.7	114.8	115.0	115.1
	total fuel		[t]	74.0	72.3	73.5	72.1
	maximum take-off		[t]	212.6	211.0	212.5	211.1

Tab. 1: Design parameters of the four TSA optimisation results.

				DLR-F11 baseline design without canard		
				a)	b)	c)
objective function (L/D*M)				17.971	18.409	18.078
cruise Mach number				0.8351	0.8463	0.8365
aerodynamics:	Lift:	wing		0.4582	0.4199	0.4527
		htp		-0.0189	0.0160	-0.0146
		fuselage		0.0649	0.0630	0.0651
		total		0.5042	0.4989	0.5032
	drag:	induced		0.00961	0.00909	0.00947
		friction		0.01254	0.01254	0.01252
		wave		0.00002	0.00003	0.00003
		interference		0.00126	0.00126	0.00126
		total		0.02343	0.02294	0.02328
	L/D			21.52	21.75	21.61
stability:	x-pos. centre of gravity		[m]	27.59	29.76	27.34
	x-pos. neutral point		[m]	30.46	30.44	29.95
	static margin		[%]	42.2	10.0	38.4
weights:	operating empty		[t]	114.4	114.4	114.4
	total fuel		[t]	73.6	72.1	73.3
	maximum take-off		[t]	211.9	210.4	211.6
geometry:	wing x-position		[m]	19.07	19.07	18.58
	htp reference area		[m^2]	70.57	70.57	68.23

Tab. 2: Design parameters of the optimised DLR-F11 configuration without canard: without modification a), with variable position of the centre of gravity b) and variable wing position and constant tailplane volume c).