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INFLUENCE OF REAR END SPOILER ON AERODYNAMIC CHARACTERISTICS AND WAKE STRUCTURE OF A HELICOPTER FUSELAGE

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Abstract

Earlier experimental study of the flow field around a helicopter fuselage revealed the existence of strong contra-rotating longitudinal vortices emanating at the side edges of the upswept rear end. The axis of these vortices is aligned roughly along that of the tail boom.

As these flow phenomena can significantly effect the aerodynamic characteristics of the fuselage and tail rotor effectiveness, inhibition or control of the vortices generated is of interest. Results of the effect of a spoiler, located at the start of rear end upsweep, on vortex formation, aerodynamic characteristics and pressure distribution on fuselage are presented and discussed.

Experimental results obtained with a 1:7 scale model fuselage are:

Six component force measurements, pressure distribution on body surface and three component velocity distribution in the fuselage wake.

Parameters varied were spoiler span, angle of incidence and yaw. All measurements were carried out without rotor flow simulation.

1. Introduction

The flow around a bluff body such as a helicopter fuselage is extremely complex and three dimensional. The various flow phenomena which are created through interaction of rotor, fuselage and tail rotor flows are not well understood. Sophisticated experimental techniques are needed to investigate the basically unsteady flow. Lack of this information hampers theoretical analysis.

As the parasite drag of a helicopter fuselage may account for up to 20% of the total drag, increased effort is necessary to analyse the drag creating mechanisms. The upswept rear end of helicopter fuselage almost always creates a large region of separated flow which may also be flanked by strong longitudinal vortices. Flow management in the wake region through add on devices such as spoilers and strakes bears promise of reducing the pressure drag and improving lift (and flight stability) through fixing separation lines and avoidance of longitudinal vortices [1,2].

The present results are in pursuance of an earlier study [3] to gain insight into the physical phenomena of a helicopter fuselage flow field.

2. Experimental arrangement and test procedure

The experimental investigations on the 1:7 scale helicopter model fuselage with cowl and spoiler, Figure 1, were performed in the open test section of the DFVLR low speed windtunnel in Göttingen [4]. The spoilers were attached on the fuselage underside at the begin of rear end upsweep, 741 mm away from model nose, in vicinity of section 13. The spoilers were of aluminium sheet segments, 0.7 mm thick and 15 mm high. Starting with the full span spoiler of 272 mm width, three/four-, half- and quarter span spoiler configurations were realised through removing the mid segments. A three/four span spoiler consisted of two elements 102 mm wide, arranged on either side of the plane of symmetry; a half span spoiler of elements 68 mm wide and quarter span spoiler of elements 34 mm wide respectively.

One half of the model was instrumented with pressure taps distributed over 24 body cross sections, Figure 1c. Scanivalves for pressure data acquisition were installed inside the model. A ten-hole directional probe was employed for the flow field measurements. For the data acquisition of the force measurements a strain gauge balance was used. For the tests, the model was mounted upside down on a sting, about 2 m behind the windtunnel nozzle. Further details about experimental arrangement and test procedure are given in [3].

3. Discussion of experimental results

From the extensive experimental data a representative set of results for cruise condition (at $\alpha = -5°$) is presented here. The influence of the main and tail rotor flow is ignored.

An analysis of the wake structure is attempted on the basis of the distribution of velocity vector V_{yz}, pressure distribution and six-component force measurement.

Wake survey

A summary of wake survey results is given in an isometric representation in Figure 2 for the parameter spoiler span. Velocity vector plots of V_{yz} in the two traverse planes $X_A/L = -0.01$ and $X_A/L = -0.31$ are shown for the cruise condition angle of incidence $\alpha = -5°$ and a yaw angle $\beta = -15°$. It is seen that the wake is characterised by a pair of fully developed contra-rotating longitudinal vortices. The sense of rotation of the vortices is such that an inclined upwash is created. This upwash inclination results from model yaw as will be discussed later.

For the clean configuration, both vortices are apparently of same strength, the luff side vortex lying lower as the lee side vortex. This trend continues downtream as noticeable in the velocity vector plot for $X_A/L = -0.31$.

Under same yaw condition, a quarter span spoiler effects a further lowering of the luff side vortex, increasing its intensity but diffusing the lee side vortex. With full span spoiler, both vortices lie over one another creating a horizontal side wash in the tail rotor region.

A more clear impression of the shift in the location of luff- and lee side vortices with spoiler span and the resulting cross flow field at tail rotor position ($X_A/L = -0.01$) is conveyed in Figure 3.

Effect of flow yaw on the location of the longitudinal vortices is shown in Figure 4. Considering the clean configuration, with increasing yaw (top row), the lee side vortex position is raised and luff side vortex lowered, so that at tail rotor location the initially vertical upwash is progressively inclined. A reason for this is the vortex attenuating flow, generated at slant side edges of model front interacting with the flow at rear end. The luff side vortex strength is seen to increase with yaw.

Effect of a full span spoiler on vortex formation is depicted in the vertical columns of Figure 4. For the zero yaw condition the presence of the spoiler practically eliminates the vortex formation and a uniform flow field is present at the tail rotor location. As mentioned earlier the effect of a full span spoiler at yaw angle of -15° can be beneficial as the flow at tail rotor location is a horizontal side wash.

Pressure distributions

Pressure distributions over fuselage for cruise incidence angle $\alpha = -5°$ is given in Figures 5 and 6 for yaw angles $\beta = 0$ and $\beta = -15°$. The measured pressure values are plotted over fuselage cross section contour and connected with spline curves.

Upstream of spoiler location, in sections 19 to 16, the pressure distribution remains unaltered, with or without spoiler, also under yawed flow. Presence of the spoiler is felt about 75 mm ($X/L = 0.05$) ahead of its location, Figure 6, section 14.

Of particular interest was the pressure distribution on the upswept rear end, which is shown in Figure 7 for the zero yaw and $\beta = -15°$ flow condition. Parameter varied was the spoiler span in steps of quarter span, starting from the clean configuration. The pressure distribution for the clean configuration shows (first column from bottom to top) peaks in the sections 12 and 7 for the zero yaw flow indicating that the vortex generated at the lower edge of the upsweep is carried upwards towards model upper surface i.e. the vortex axis is inclined more steeply than the rear end upsweep.

A noteworthy inference follows from comparison of the pressure distribution results of a horizontal row of Figure 7. With increasing spoiler span, the low pressure on model base is reduced, e.g. section 13, zero yaw flow. As spoiler span has little effect on surface pressure distribution ahead of spoiler, a consequence of this is a net improvement of the total lift experienced by the fuselage. As will be shown later, this is confirmed by the force measurement results.

Results of pressure distribution correlate with those of the wake survey in Figures 3 and 4. The earlier mentioned raising and lowering of the lee and luff side vortex axes is reflected in Figure 7 as asymmetric pressure peaks of section 7.

Total pressure distribution in tail rotor plane

Results of total pressure distribution along a vertical line through tail end are shown in Figure 4. Also indicated through a point is the position of the tailboom tip. Together with the velocity vector plots, these results give information about the flow field in which the tail rotor and fin operate. The total pressure drop p_T/q_∞ above the tail end, Figures 4a to f, is caused by the wake of the cowl and tailboom. The longitudinal vortices, present for the clean configuration, apparently cause a quick total pressure recovery in the fuselage wake as visible in Figures 4a and b. For the yaw angle $\beta = -15°$ the clean configuration exhibits a very unfavourable total pressure distribution at the tail rotor location together with an inclined cross flow field generated by the longitudinal vortices.

Effect of a full span spoiler on the total pressure distribution is shown in Figures 4d to f. The pressure distribution is characterized by two pressure loss peaks resulting from the cowl tailboom and the spoiler itself. The spoiler effects a smoothing of the pressure deficit at rotor location for $\beta = -15°$, Figure 4f. Results of Figure 4 are helpful in the decision for the proper location of tail rotor and control surfaces.

Force measurements

The effects of spoiler span on the drag and lift characteristics of the helicopter fuselage are represented in Figure 8. For the zero yaw flow condition, Figure 8a, in the incidence range between -5° and 15°, the drag C_D is progressively increased with spoiler span. Apart from increase in projected area due to model incidence, positive incidence with spoiler on fixes the lower edge of fuselage wake and consequently its vertical extension increases, accounting for the drag rise. With negative incidence the spoiler is shielded by the model front so that a wake enlargement is not so effectively enforced as above. At an incidence of $\alpha = -7°$ all spoiler configurations have about the same drag value.

Lift characteristics of the fuselage for the various spoiler configurations are plotted in the lower half of Figure 8a. For the incidence angle of about -7°, the interesting result to note is the sizable improvement in the lift experienced by the fuselage with a full span spoiler over that for the clean configuration. This gain in lift occurs without the penalty of a higher drag as observed above.

Finally, in Figure 8b and c, the influence of yaw on drag and lift characteristics of the fuselage is detailed. With positive incidence the drag increment with spoiler span is approximately maintained over the yaw angle range investigated. The modest rise in these values, or even a decrease as in the case of $\alpha = -15°$, is retained over the yaw angle range between $\beta = 0$ and $\beta = -7°$.

Significant effect of spoiler on lift, Figure 8c, is the increment in lift coefficient. For incidence angles between -7° and 10°, the addition of a full span spoiler changes the lift experienced from negative to positive values. This behaviour is maintained over a yaw angle range of $\beta = 0$ to -20°.

Conclusions

1. Wake of the helicopter model fuselage is characterized by two longitudinal vortices whose axes are aligned roughly with the tailboom.

2. With yaw, the leeward vortex axis is raised and the luffward vortex axis is lowered.

3. A full span spoiler situated at the start of rear end upsweep inhibits the vortex formation of longitudinal vortices; with strong yaw, these vortices reappear but are arranged with their axes over one another creating a more favourable flow field in tail rotor plane.

4. Pressure distribution on upswept rear end surface confirms the generation of longitudinal vortices at the slant edge and pressure recovery at upswept surface due to spoiler.

5. For $\alpha = -7°$, i.e. near cruise condition, and zero yaw, the installation of a full span spoiler remarkable improves the fuselage lift without imposing a drag penalty.

References

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4 F.W. Riegels, W. Wuest, Der 3-m-Windkanal der Aerodynamischen Versuchsanstalt Göttingen, Zeitschrift für Flugwissenschaften Nr. 9, pp. 222-228, 1961.

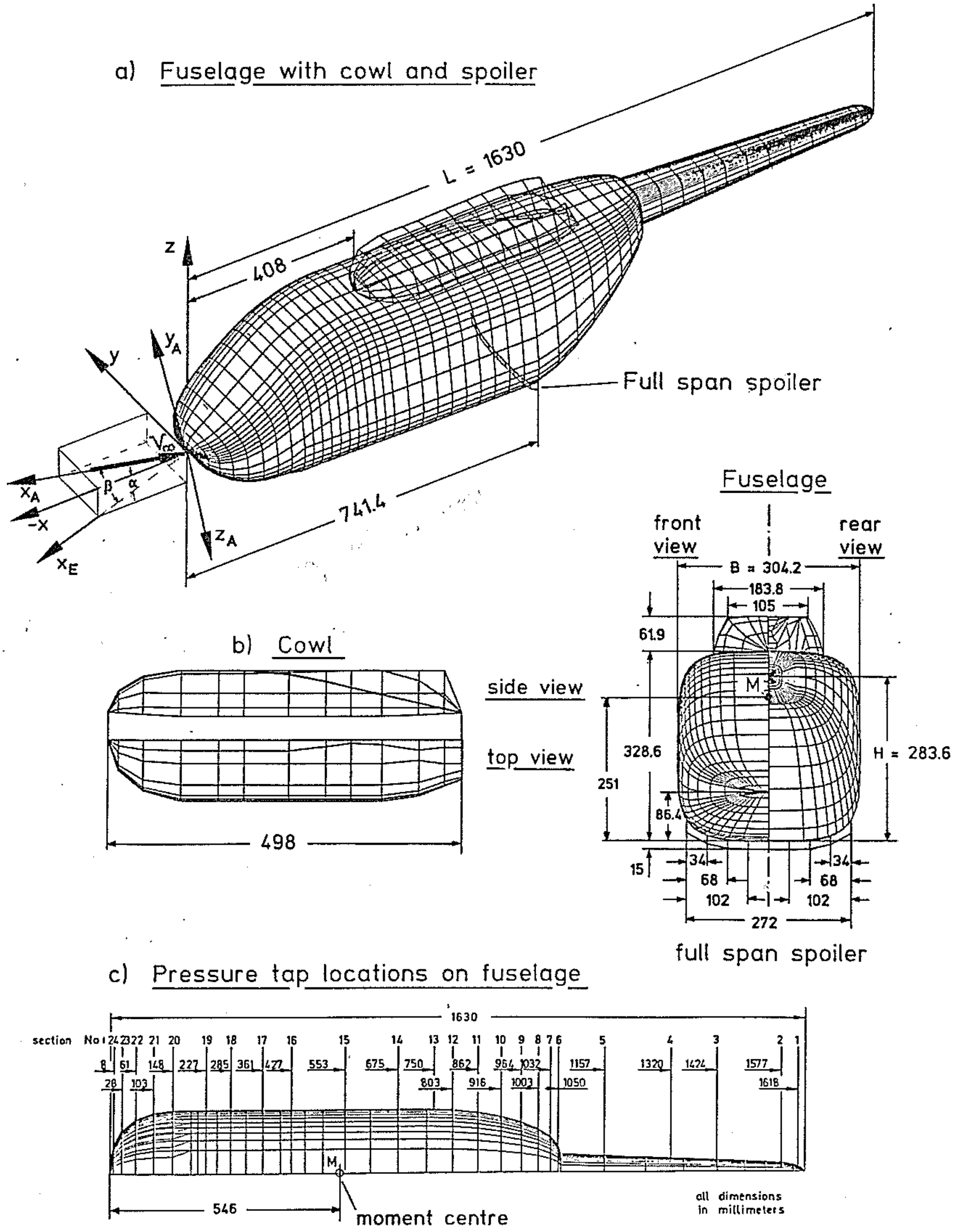

Figure 1 Model Geometry

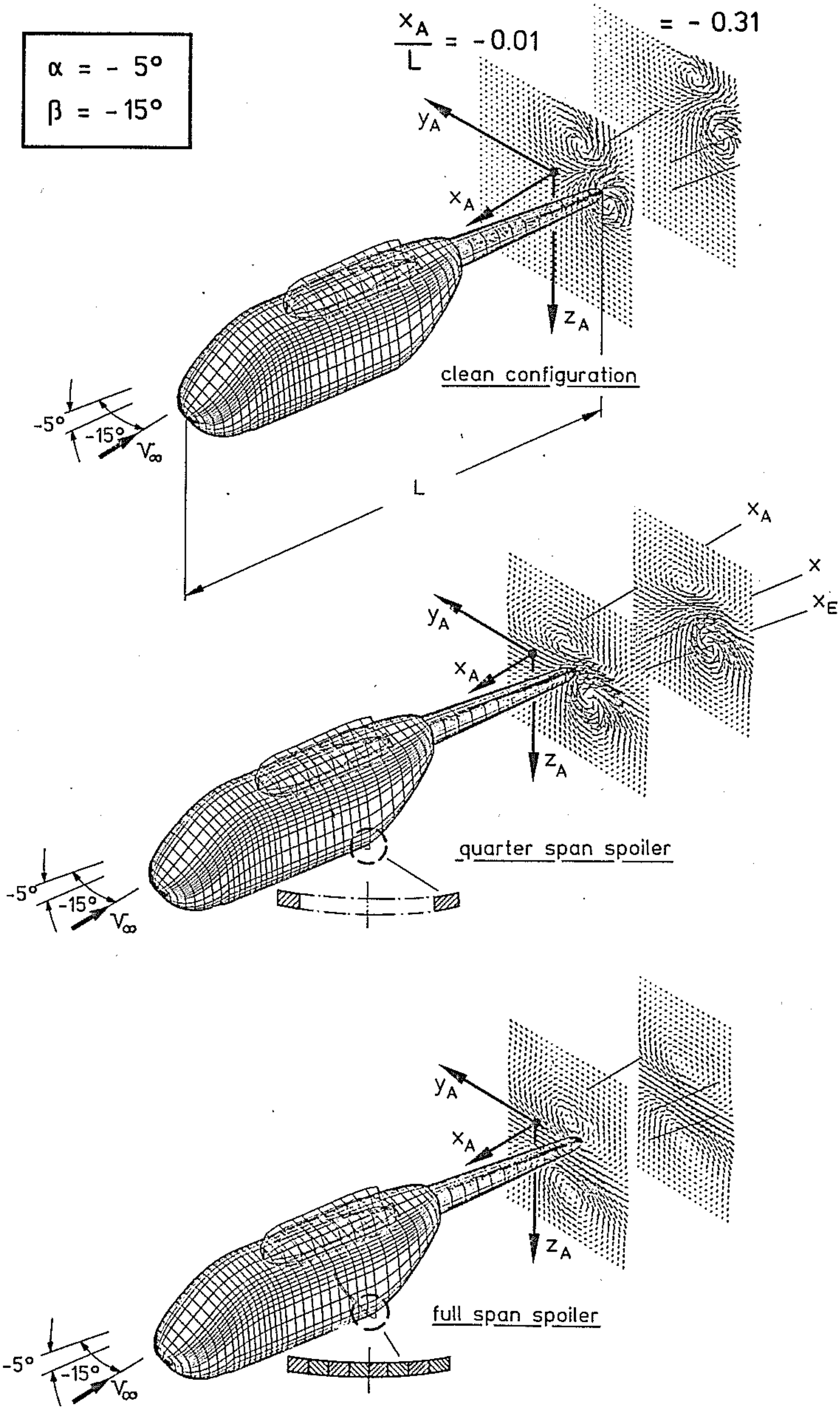

Figure 2 Influence of spoiler span on wake structure

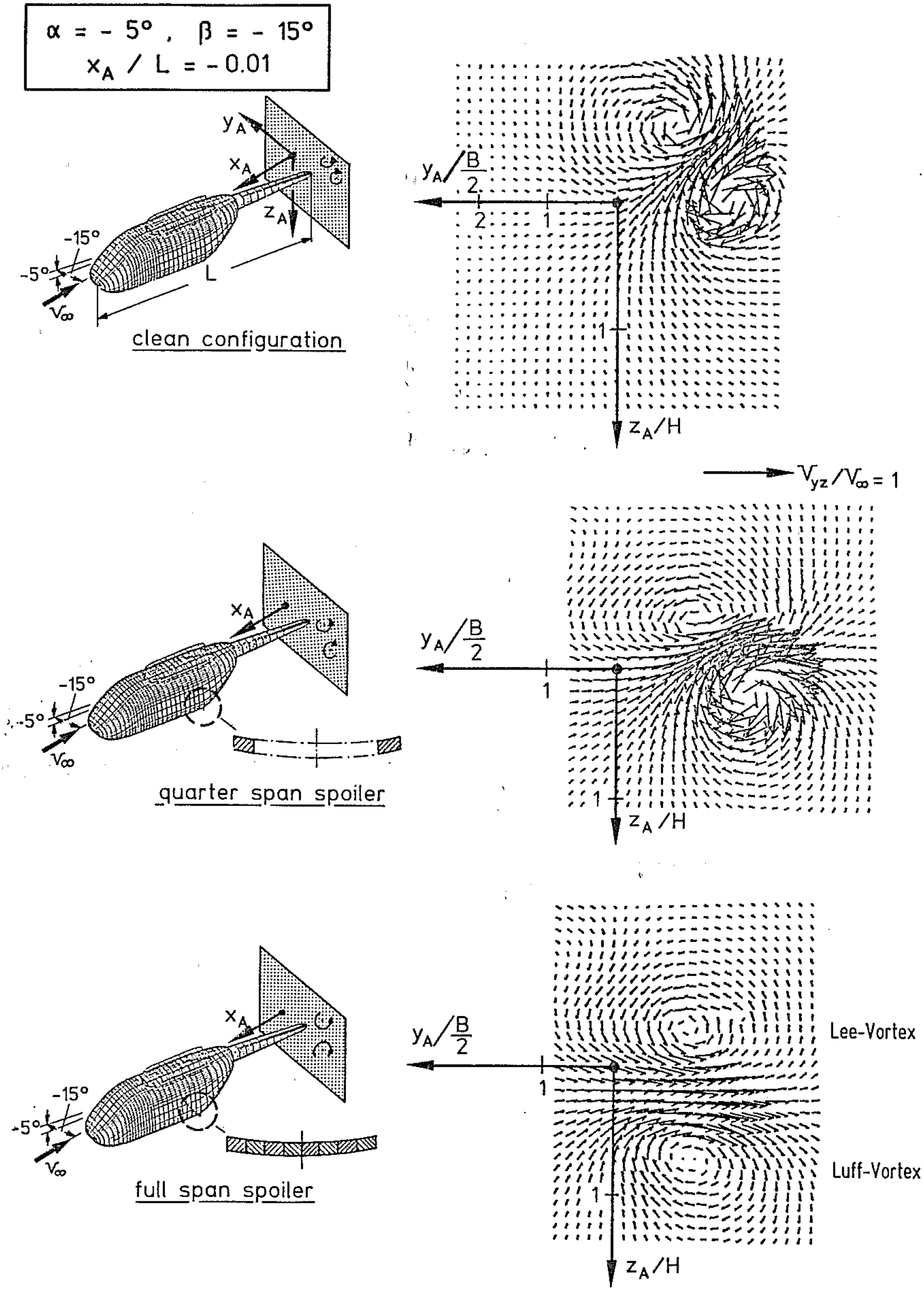

Figure 3 Influence of spoiler span on wake structure in tail rotor region

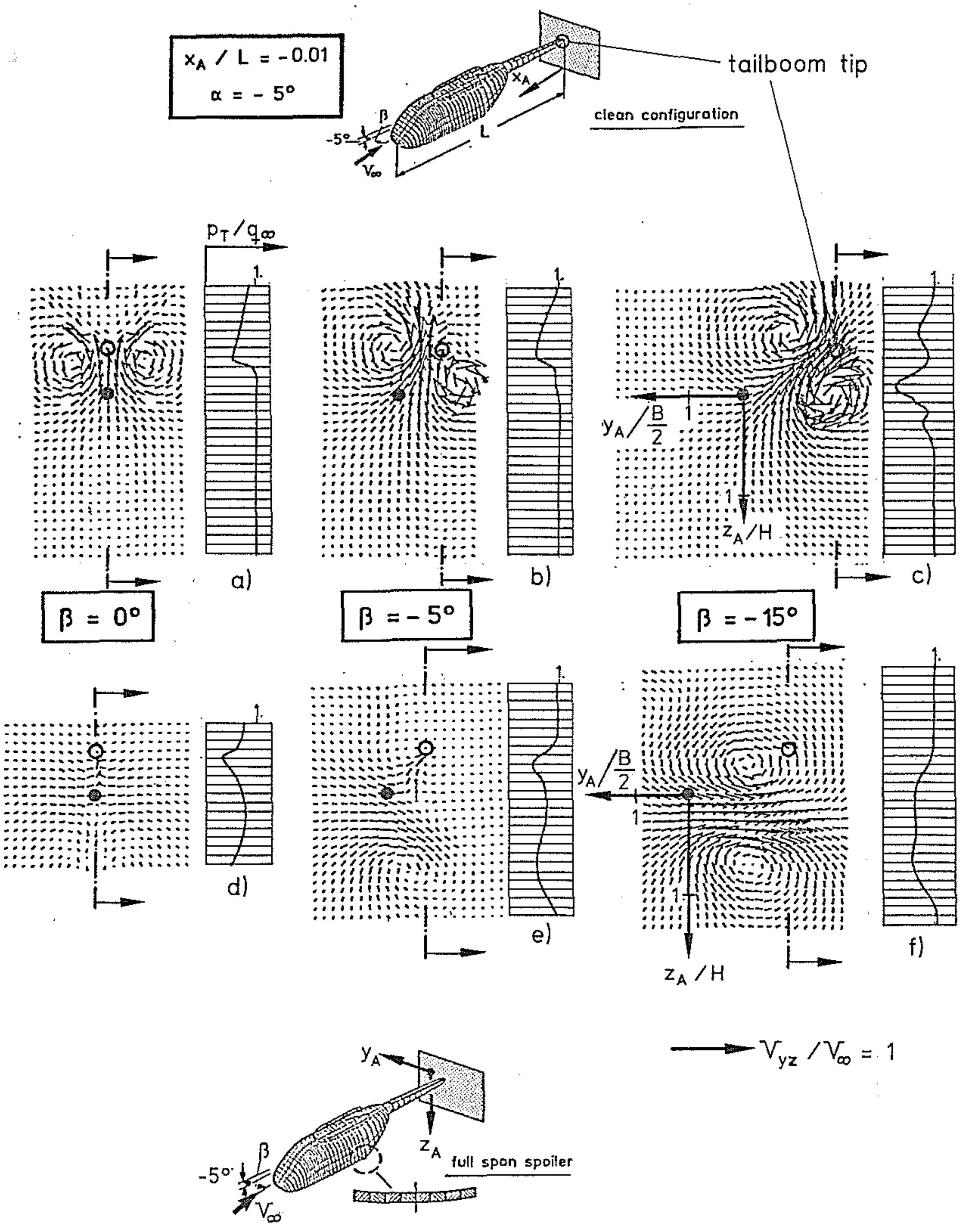

Figure 4 Influence of yaw on wake strukture

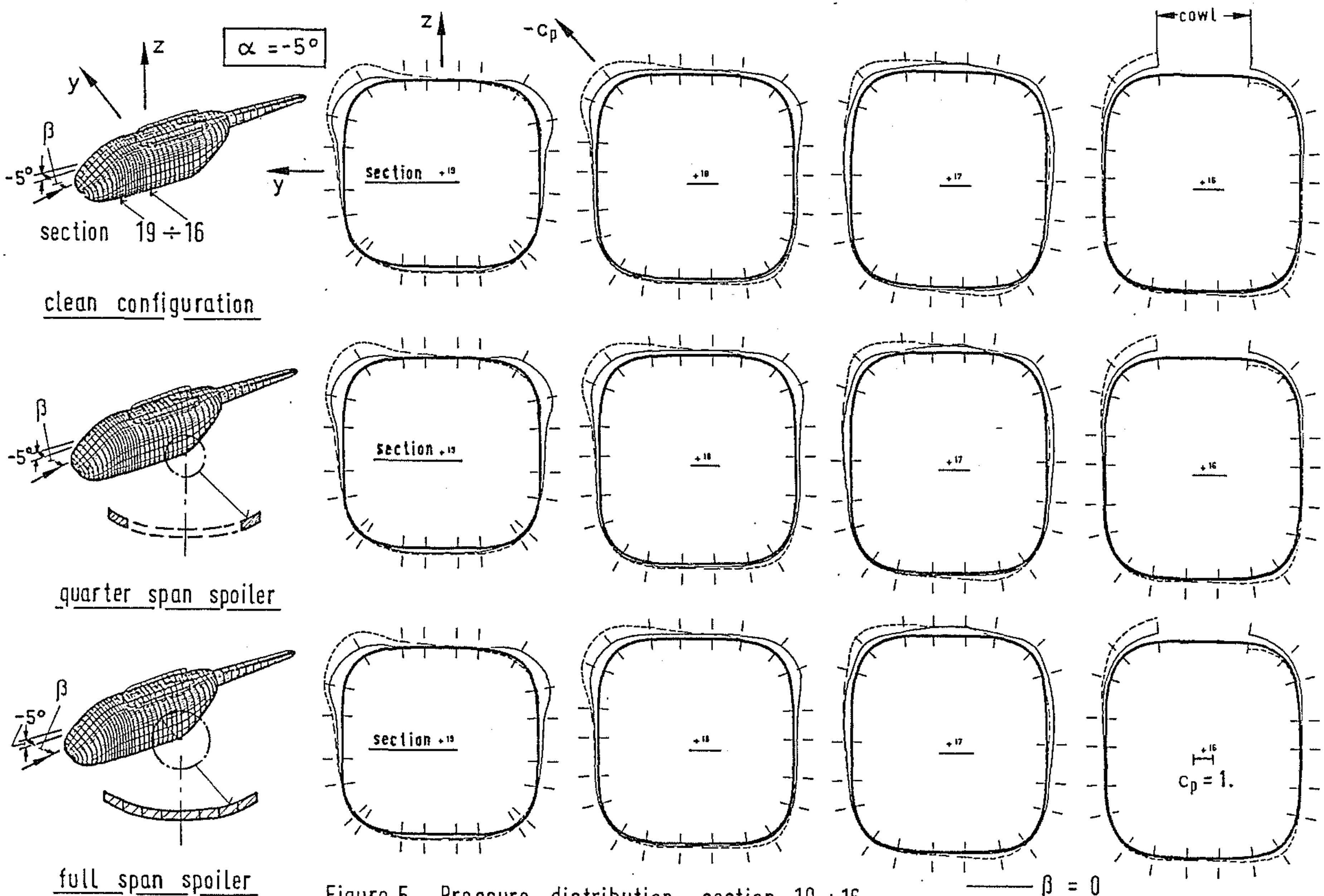

Figure 5 Pressure distribution, section 19 ÷ 16

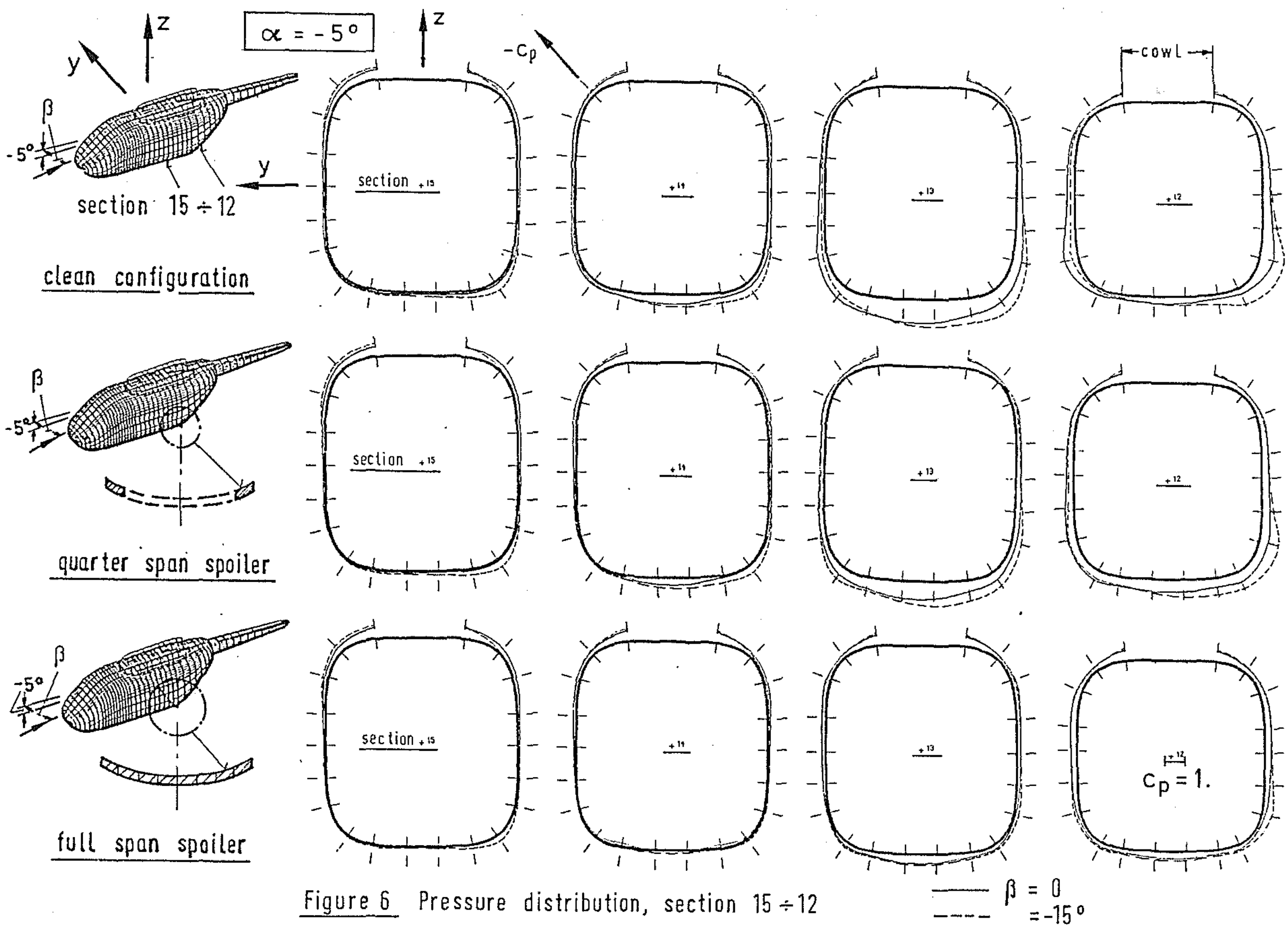

Figure 6 Pressure distribution, section 15 ÷ 12

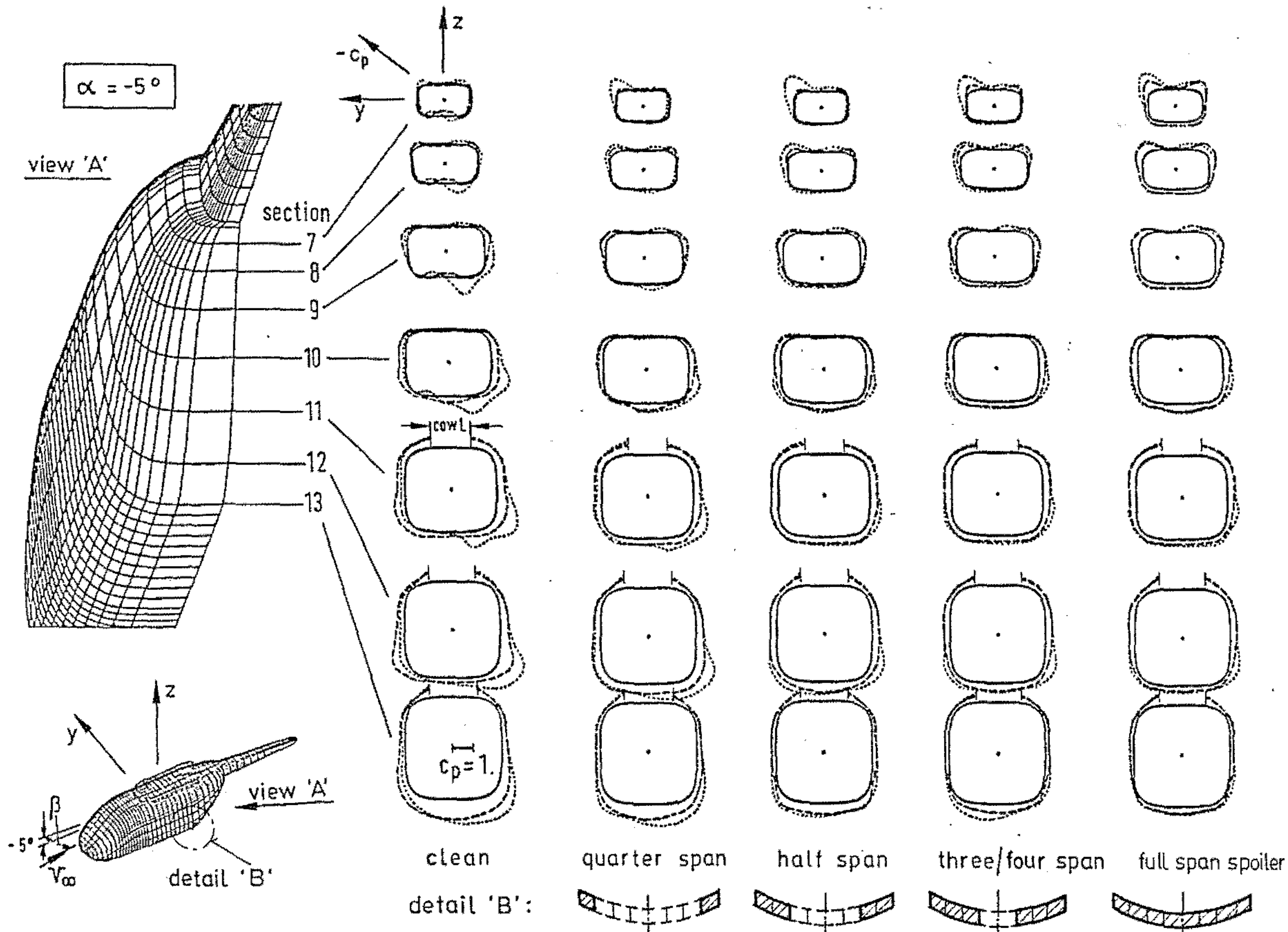

Figure 7 Pressure distribution in the base region

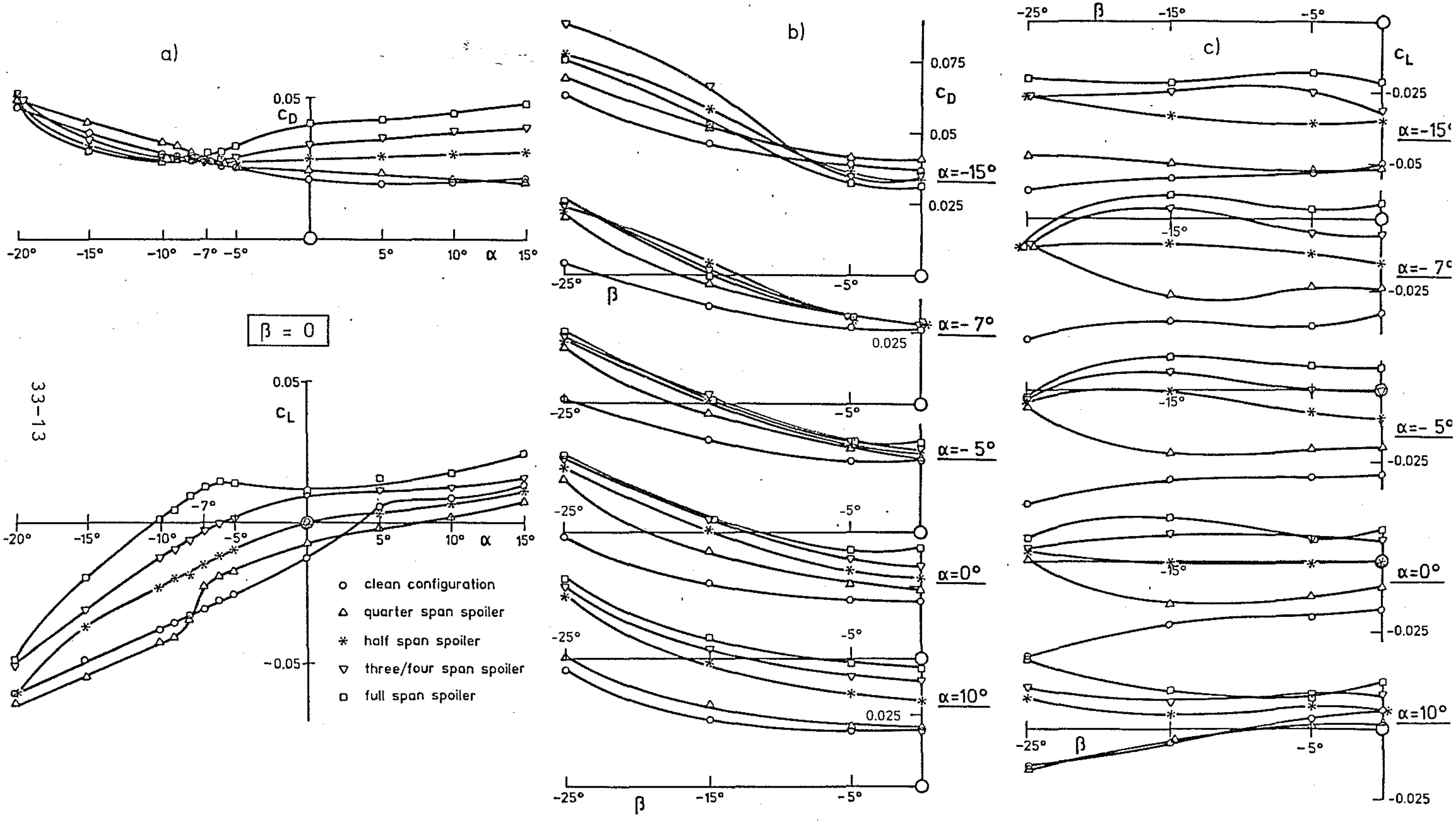

Figure 8 Variation of aerodynamic coefficients C_D and C_L