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# PROTECTION AGAINST WING ICING FOR AIRBUS A300 AND A310

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## STANDARD TITLE PAGE

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| 16. Abstract<br>To improve economy of operation, it is now planned to modify the antiicing system used on the A300 Airbus wing. Thus, for the A310 Airbus, the deicing system will be applied to only half the wing length. Other essential modifications are a substantial simplification of the warm-air system and discontinuation of the use of a double wall in slats. |                                                      |                                                            |           |
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**Abstract (technological-scientific neutrally-oriented summary):**

The formation of ice deposits on airplane components can affect flight safety. Endangered components are above all wings, tail assembly, power-plant inlets, windows, and probes.

The installation of icing-protection devices can prevent the formation of ice deposits to a large extent. The positive effects of these installations are counteracted by negative consequences with respect to economic considerations for the airplane (energy consumption, weight of the installation, fabrication- and maintenance costs etc.). Therefore, in modern airplanes, icing protection of the tail assembly as well as of the wing sections between engines and fuselage is dispensed with to an increasing degree.

In the airbus A300 and A310 provisions are made to decrease icing protection of the wings even more, and specifically to about 50% of the wing length. Furthermore the warm-air protection installation is simplified considerably compared to the present A300 installation. In particular the installation of the till now conventional double wall in the slats is discontinued.

**Key words:** icing, icing protection, ice prevention

## 1. INTRODUCTION

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The formation of ice deposits on airplane components can impair flight safety and must, therefore, be taken into account in the development and testing of airplanes. Negative effects of ice deposits are primarily:

- decrease in lift
- increase in drag
- effect on controllability
- visibility impairment as the result of ice on windows
- increase in oscillations and stresses of airplane components
- reduction in engine power because of icing of inlets
- damage to engines caused by ice deposits breaking off (ice pelting)
- failure of instrumentation.

The by far most common form of icing occurs during flight through clouds which contain supercooled water droplets. If the droplets hit airplane components, they are converted partially or wholly into ice which adheres to the surface. This process leads to the formation of ice deposits whose shape and height can vary considerably depending on icing conditions. In clouds which contain exclusively ice crystals there is little danger of icing since the ice crystals generally do not adhere to the surface if the surface is not heated.

Power plant inlets and other air inlets can ice up even on the ground if the proper ground icing conditions prevail, i.e. ground fog for a static air temperature below 0° C.

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\* Numbers in margin indicate pagination of original foreign text.

## 2. MECHANICS OF WATER COLLECTION

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The process which leads to the impacting of water droplets on airplane parts and thus to ice formation is explained in greater detail in figure 1. On a streamline of the airflow around an airfoil there are initially water droplets of varying size (figure 1, upper left). As they approach the airfoil the droplets do not follow the stream line, but move, on account of their mass inertia, on trajectories which are between the straight lines to the airfoil and the streamline. The larger the droplet size, the more the trajectories deviate from the streamlines.

The droplet trajectories are determined, neglecting gravity, from the equilibrium between inertia- and air forces. The inertia force is given by

$$\vec{K} = - V \cdot \rho_W \cdot \frac{d\vec{v}}{dt}$$

with

$V$  = droplet volume

$\rho_W$  = density of water

$\vec{v}$  = vector of the local droplet velocity

For the force of air we obtain

$$\vec{W} = -C_D \cdot F \cdot \frac{\rho_L}{2} \cdot (\vec{v}-\vec{u}) |\vec{v}-\vec{u}|$$

with

$C_D$  = drag coefficient of the droplet

$\rho_L$  = density of the air

$F$  = front surface of the droplet

$\vec{v}-\vec{u}$  = vector of the velocity difference between  
droplet- and air velocity

With

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$$F = \frac{3}{2} \frac{\gamma}{d}$$

$d$  = droplet diameter

we obtain from the equilibrium condition  $\vec{K} + \vec{D} = 0$  the differential equation of the droplet trajectories as

$$\frac{d\vec{v}}{dt} = - C_D \cdot \frac{3}{2d} \cdot \frac{\rho_L}{\rho_W} \cdot (\vec{v} - \vec{u}) \cdot |\vec{v} - \vec{u}|$$

The drag coefficient  $C_D$  of the droplet is a function of the Reynolds number of the droplet

$$Re = \frac{d}{\nu_L} \cdot |\vec{v} - \vec{u}|$$

$\nu_L$  = kinematic viscosity of air

For small values of  $Re$  (creeping movements) Stoke's law applies as an approximation

$$C_D \approx \frac{24}{Re}$$

The droplet trajectories from the above differential equation for a given case (airfoil shape, flight velocity, droplet diameter etc.) are calculated with a computer program. It contains a subroutine for calculating the air velocity field near the airfoil by means of a panel method.

An example of the computer results is shown in figure 2 for the droplet trajectories in the vicinity of the leading edge of a wing for a step near the fuselage ( $\eta = Y/S = 0.15$ ,  $S$  = half span width) and a given flight case.

From the droplet trajectories the following characteristic quantities for the water collection of the an-iced airfoil can also

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be determined:

- limits of the impact zone (upper and lower impact limits, given by tangential droplet trajectories)
- local and total collection factor (for definition of these quantities see e.g. reference 1).

For a sufficiently low surface temperature icing\* occurs in the impact zone whereby the airfoil and thus the droplet trajectories change. The height and the shape of the ice deposits that are formed depend on the icing conditions. As shown in figure 3 the low values of air total temperatures and the free water content deposits of coarse ice develop whose form corresponds somewhat to the local collection factor. When the so-called Ludlam limit (freezing factor less than 1) is exceeded one must figure with the development of clear ice deposits. These ice deposits are especially unfavorable from an aerodynamic standpoint.

### 3. ICING PROTECTION MEASURES ON THE AIRBUS A300 AND A310

Through the installation of suitable protection installations the formation of ice deposits can be avoided to a large extent. Modern airplanes are equipped almost exclusively with thermal protection devices whereby, with respect to cell and engine, warm air protective installation predominate. The layout of the protective devices is made in accordance with the meteorologic requirements specified by the licensing authorities (FAR 25: appendix C).

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\* Water that is running back can also form ice outside of the impact zone.



The positive effect of the icing protection equipment is counteracted by several consequences, which impair the economy of the airplane, e.g.

- energy consumption
- weight of the installation
- development costs
- fabrication costs
- maintenance costs

For that reason modern civilian airplanes such as the Airbus limit icing protection to a minimum which is absolutely necessary to maintain air worthiness.

Figure 4 presents a summary of the ice protection measurements employed by the Airbus A300 and A310. It must be emphasized here that elevator and rudder assemblies as well as the inner wing surfaces are unprotected.

The wings are protected against icing with hot air from the engine whereby with regard to the protected area the following apply.

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For airplanes of the type A300 which are equipped with engines from the General Electric Co. (Type CF6-50) (this is the normal case), the slats 2 and 3 are protected along their entire length. In the airplane no. 79 an A300 was equipped for the first time with engines from the Pratt & Whitney Co. of the type JT9-D. For this engine type it became necessary to reduce the hot air consumption of the wing ice protection installation; therefore, this installation was modified and the icing protection was limited to about 50% of the span width. It is planned to install the modified version starting with airplane no. 100 into each A300 (regardless of engine type).

For the A310 the wing icing protection was limited to begin with to the slats 3 and the external halves of the slat 2.

#### 4. WING ICING PROTECTION INSTALLATION

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##### 4.1 On principle

The wing ice protection installation of the Airbus A300 and the A310 is in principle an ice prevention installation with continuous heating of the surface to be protected. In this way it differs from other de-icing installations where ice deposits that are formed are removed cyclically (thermally or mechanically).

The hot air for supplying the wing de-icing installation is taken from the pneumatic system of the airplane which itself is supplied by the engine (compressor stages) or if necessary from the auxiliary engine (APU). Air temperature and air pressure in the pneumatic system are controlled and amount to in the normal case when the protective installation is turned on to about 227° C and about 3.2 bar (above atmospheric pressure).

The hot air from the pneumatic system is led through a line in the leading edge of the wing to telescopic tubes through which the hot air is passed to the slat (see figure 5). The hot air is distributed along the leading edge of the wing through so-called Piccolo tubes. The hot air streams leaving the Piccolo tubes bring about an intensive heating of the slat nose. From the space in front of the flat longeron, the so-called D-channel, the already considerably cooled air flows through a double wall (A300) into the space behind the longeron and leaves the slats through blowout openings. In the A310 the installation of the double wall was dispensed with which will be discussed further later on.

## 4.2 Installation schemes

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Figure 6 shows the wing icing protection installation of the A300 before the above-mentioned modifications. The hot air from the pneumatic system (shown cross-hatched) is passed to the protective installation through pressure control valves ①. These pressure control valves reduce the pressure in the pneumatic system from about 3.2 bar (above atmospheric pressure) to about 1.4 bar (above atmospheric pressure). Then, as already mentioned, the hot air is passed to the slats. In the normal case each of the two wings is supplied by its own engine. In case of trouble where one of the two valves does not open the affected wing is supplied through the cross connection ⑤ from the other side.

Figure 7 shows the protection installation after the modification. The following important changes must be stressed:

- restriction of the protected wing surface area to slat 3 and to about one half of slat 2
- elimination of the cross connection for the protection device
- the replacement of the pressure control valve by relatively cheap and reliable open-shut valves.

In order to retain the original operational readiness after elimination of the cross connection of this installation two valves are installed in parallel on each wing. If the installation is supplied by the engine (normal case), only one valve per wing is opened. If they are supplied by the APU both valves are opened. Orifices are installed downstream of the valves in order to limit the air flow.

In the A310 the protection installation has been simplified still further, see figure 8. Only one telescopic tube is installed per wing; telescopic tubes of the slats 2 are eliminated. The slats

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2 are supplied by flexible cross connections ⑤ between slats 2 and 3.

#### 4.3 Reduction in weight

Compared to the original A300 protection installation a minimum weight of about 80 kg. is obtained for the protection installation of the A310.

#### 4.4 Reduction of the hot air flow

Because of the reduction of the protected wing surface area to about 50% of the span width the requirement of hot air of the ice protection installation is reduced. Figure 9 shows the entire hot air flow of the protective installation of the A300 and A310 plotted against altitude (supply from the engines). An average reduction of the hot air requirement of 18% is realized ( the A310 figures are preliminary).

### 5. ELIMINATION OF THE DOUBLE WALL IN THE SLATS OF THE A310

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#### 5.1 Preliminary remarks

Figure 10 shows on top the passage of the hot air in the slats of the A300. The hot air streams exiting from the three rows of holes of the Piccolo tube hit the inner surface of the leading edge of the wing. Here, under icing conditions the air is cooled from about 200°C in the Piccolo tube to about 100°C. The cooled air is collected in the space in front of the longeron, so-called D-channel, and flows through a double wall along the upper side of the wing into the rear space of the slat where it is cooled by about 50° C.

The double wall consists of the outer skin of the slat and a curved sheet metal piece which is cemented to the outer skin.

In order to reduce fabrication costs it was suggested to eliminate for the A310 the installation of this sheet metal piece. The slat's upper side was to be heated as shown in figure 10 by a wall stream which is formed behind an air slot on the front longeron.

The decision to eliminate the double wall requires theoretical and experimental investigations.

## 5.2 Theoretical bases

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Heating of the slats in the A310 is done in such a way that slat areas to be protected against icing remain free of ice during idle and cruise and that, under extreme conditions, only minimal ice deposits are formed which can be neglected aerodynamically. This means that the impacting water must be evaporated in the protected areas to an overwhelming degree at the slat upper surface. The heating power required for this can be determined from the heat balance at the outer skin of the slat.

Figure 11 shows the heat balance at an element of area of a wet outer skin for a surface temperature  $> 0^{\circ}\text{C}$ . The area elements have a length  $\Delta S$  (in the direction of wing depth) and a width of one length unit. The temperature drop in the outer skin and in the water film normal to the surface can be taken to be negligibly small. In the stationary case the local heat flux  $\dot{q}_i$  (dimension: power per unit area) flowing from the interior to the outer skin is equal to the sum of the following heat fluxes:

a) heat flux by convection

$$\dot{q}_k = \alpha_a (\vartheta_0 - \vartheta_1 - \eta_r \cdot \frac{u_1^2}{2c_p})$$

with

$\alpha_a$  = outer heat transfer coefficient

$\vartheta_0$  = surface temperature

$\vartheta_1$  = local air temperature at the edge of the boundary layer

$u_1$  = local air velocity at the edge of the boundary layer

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$\eta_r$  = local recovery factor

$c_p$  = specific heat of air at constant pressure

b) Heat flow resulting from evaporation of the water

$$\dot{q}_v = 0,62 \cdot \frac{\alpha_a}{c_p} \cdot L_0 \cdot K \cdot \frac{e_0 - e_1}{p_1 - e_0}$$

with

$L_0$  = heat of vaporization of water at  $\vartheta_0$

$K$  = wetting factor

$e_0$  = saturation vapor pressure of water at  $\vartheta_0$

$e_1$  = local vapor pressure at edge of boundary layer

$p_1$  = local static pressure at edge of boundary layer

The following limiting condition applies

$$\dot{q}_v \leq L_0 \cdot (\dot{m}_w + \dot{m}_w')$$

with

$\dot{m}_w$  = locally impacting water stream (through droplet collection)

$\dot{m}_w'$  = water stream transported by the water film

- c) heat flux resulting from heating of impacting water

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$$\dot{q}_c = \dot{m}_w \cdot c_w \cdot (\vartheta_o - \vartheta_\infty)$$

with

$c_w$  = specific heat of water

$\vartheta_\infty$  = static air temperature in the free stream

- d) heat flux resulting from kinetic energy of the droplets

$$\dot{q}_t = - \dot{m}_w \cdot \frac{u_\infty^2}{2c_w}$$

$u_\infty$  = air velocity in the free stream

- e) heat flux transferred by the water film

$$\dot{q}_f = \dot{m}'_w \cdot c_w \cdot \frac{d\vartheta_o}{ds}$$

- f) heat flux resulting from heat conduction into the outer skin

$$\dot{q}_1 = - \lambda_M \cdot a \cdot \frac{d^2 \vartheta_o}{ds^2}$$

with

$\lambda_M$  = heat conductivity of the outer skin

$a$  = thickness of the outer skin.

For the A310 slat the evaporation heat flux in the impact zone ( $K = 1$ ) predominates strongly. Outside of the impact zone ( $K \approx 0.2$ ) this heat flux is relatively small and about equal to the heat flux by convection.

The upper side of the slat in the area of the double wall is outside of the impact zone. Thus the heating power is conducted away to a considerable degree by convection without doing any

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useful work. Thus it is important to concentrate the heat influx as far as possible on the impact zone. It is less desirable to attain a thermal efficiency as high as possible outside of the impact zone if this is connected with substantial fabrication costs.

This consideration led to the suggestion to abandon the double wall in the A310. However, it was first necessary to examine the heat transfer from the wall stream to the outer skin as compared to that for the double wall.

### 5.3 Laboratory investigation for determining the internal heat transfer

To determine the heat transfer from a wall stream to the outer skin at the slat upper side comparative measurements were made with an A300 slat model with and without double wall.

Figure 12 shows the model including the sensors. The model, about 400 mm wide, was cut out of an original A300 slat and was sealed by means of side plates. To simulate the outer heat outflow a sheetmetal piece was attached to the upper side so that an air slot with an open width of 8 mm resulted. Cold air was blown through this air slot. The hot air was obtained from an electrical air heater with temperature control.

Measurements were made for several values of cold air - as well as hot-air flux.

Figure 13 shows a typical result of a laboratory test. The power density at the upper side of the slat is shown with and without double wall. One can see that elimination of the double wall reduces the total power at the upper side of the slat by only about 10%.

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## 5.4 Effects

In figure 14 the power density at the slat is shown for a flight case in which relatively high requirements were made for the performance of the protective installation. The total power density and the contribution of evaporation are plotted against the surface distance from the lower trailing edge of the slat.

The cross-hatched areas represent the reduction resulting from the elimination of the double wall. The reduction of the entire evaporation power amounts to only about 5%. In order to avoid this reduction the flow rate of the hot air must be increased by about 6%. This increases the fuel consumption for a typical flight where the protective installation is operated for 12 minutes (20% of the flight duration) by about 3 kg. Since the elimination of the double wall produced a weight saving of about 6 kg, the economy of the airplane was maintained for the operator. The fabrication and maintenance costs will be reduced considerably.

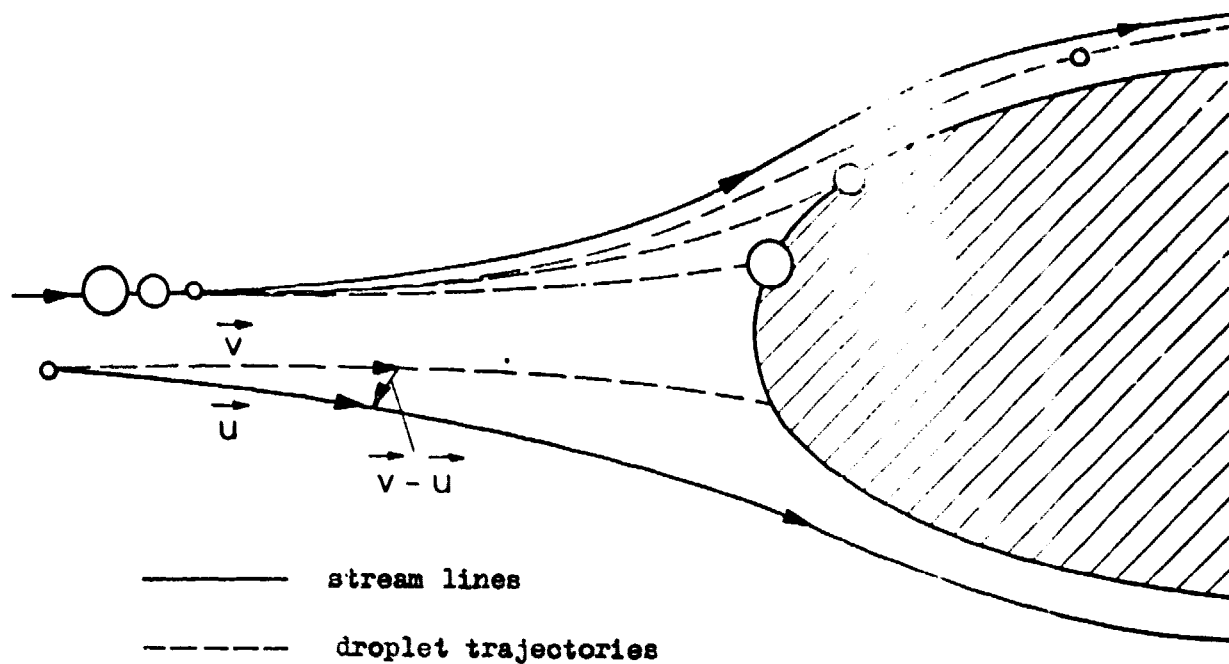
## 6. SUMMARIZING SUGGESTION

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The icing protection installation for the wings of the A310 is still in the development stage. Thus all the relevant information given in this presentation must be considered as being preliminary. It should be especially emphasized that the increase in hot-air flow rate resulting from the elimination of the double wall does not mean, in any way, that the hot-air flow rate of the A300 with JT9-D engines was exceeded.

## REFERENCES

1. D.T. Bowden, A.E. Gensemer and C.A. Keen,  
Engineering Summary of Airframe Icing  
Technical Data, FAA Technical Report ADS-4 (1963)



inertia force

$$\vec{K} = - V_j \rho_w \cdot \frac{d\vec{v}}{dt}$$

air force

$$\vec{W} = - C_D \cdot \frac{3V}{2d} \cdot \frac{\rho_L}{2} \cdot (\vec{v} - \vec{u}) \cdot |\vec{v} - \vec{u}|$$

$$\vec{K} + \vec{W} = 0$$

$$\Rightarrow \boxed{\frac{d\vec{v}}{dt} = - C_D \cdot \frac{3}{4d} \cdot \frac{\rho_L}{\rho_w} (\vec{v} - \vec{u}) \cdot |\vec{v} - \vec{u}|}$$

$$\text{with } C_D = f(\text{Re}) \quad , \quad \text{Re} = \frac{d}{\nu_L} \cdot |\vec{v} - \vec{u}|$$

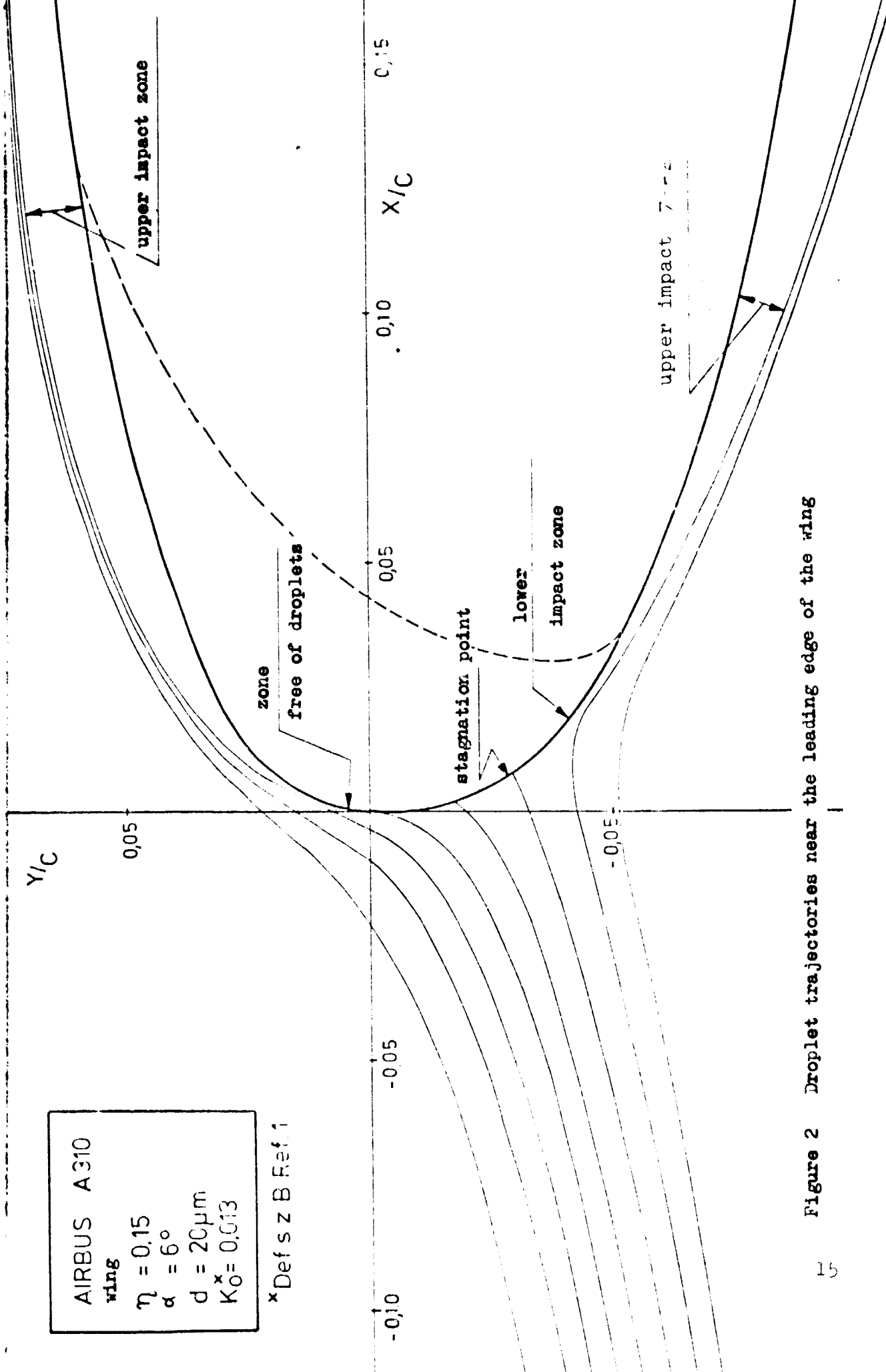
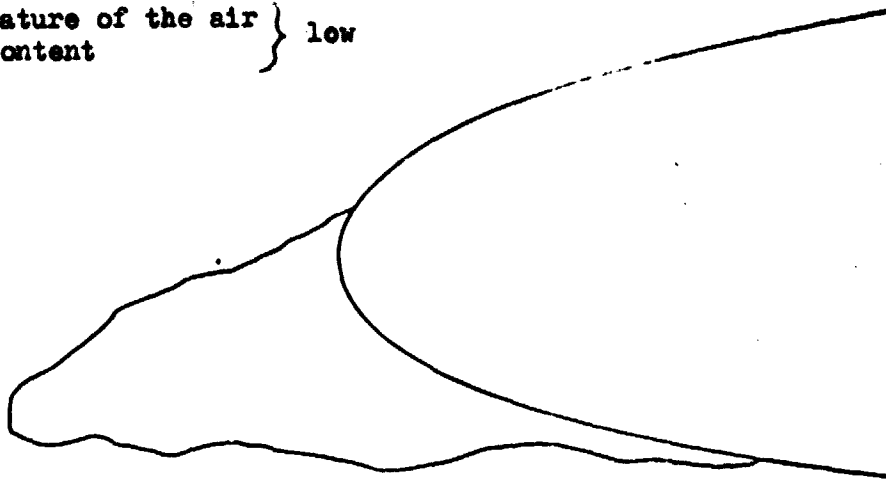


Figure 2 Droplet trajectories near the leading edge of the wing

coarse ice  
total temperature of the air } low  
free water content



clear ice  
total temperature of the air } high (Ludlam limit exceeded)  
free water content

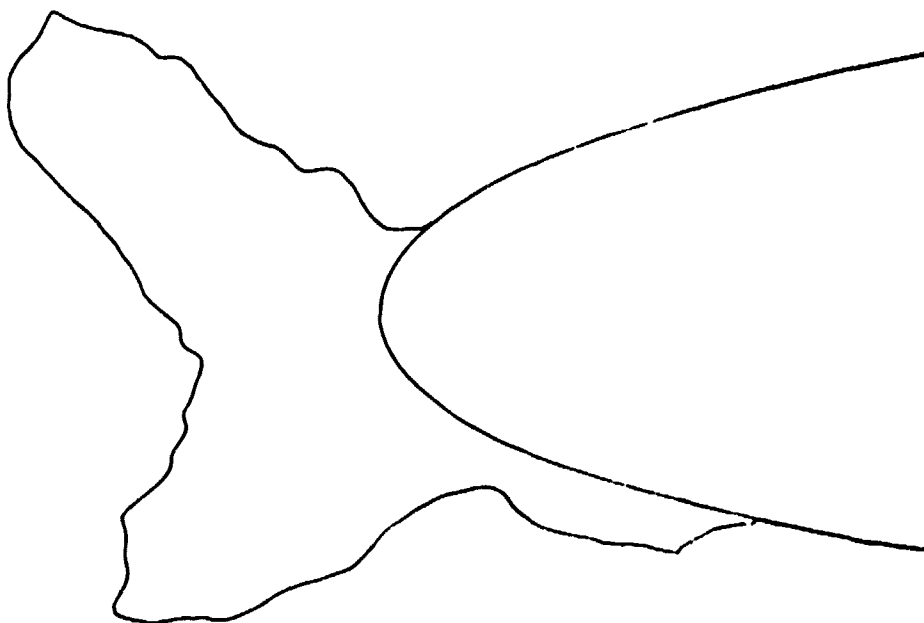


Figure 3 Typical ice forms

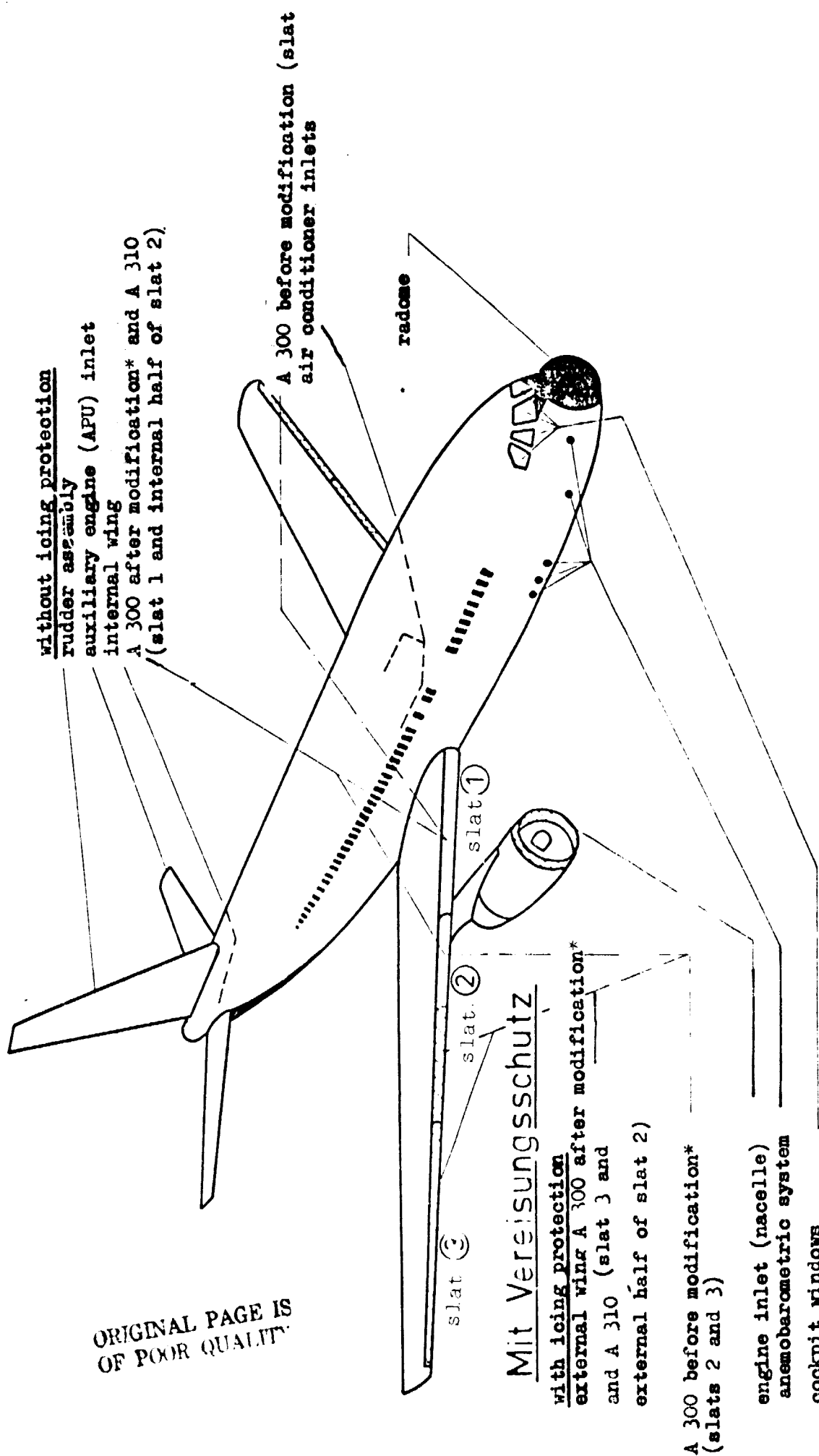


Figure 4 Airbus A300 and A310 - summary of icing protection measures

\* modification of the protection installation against wing icing

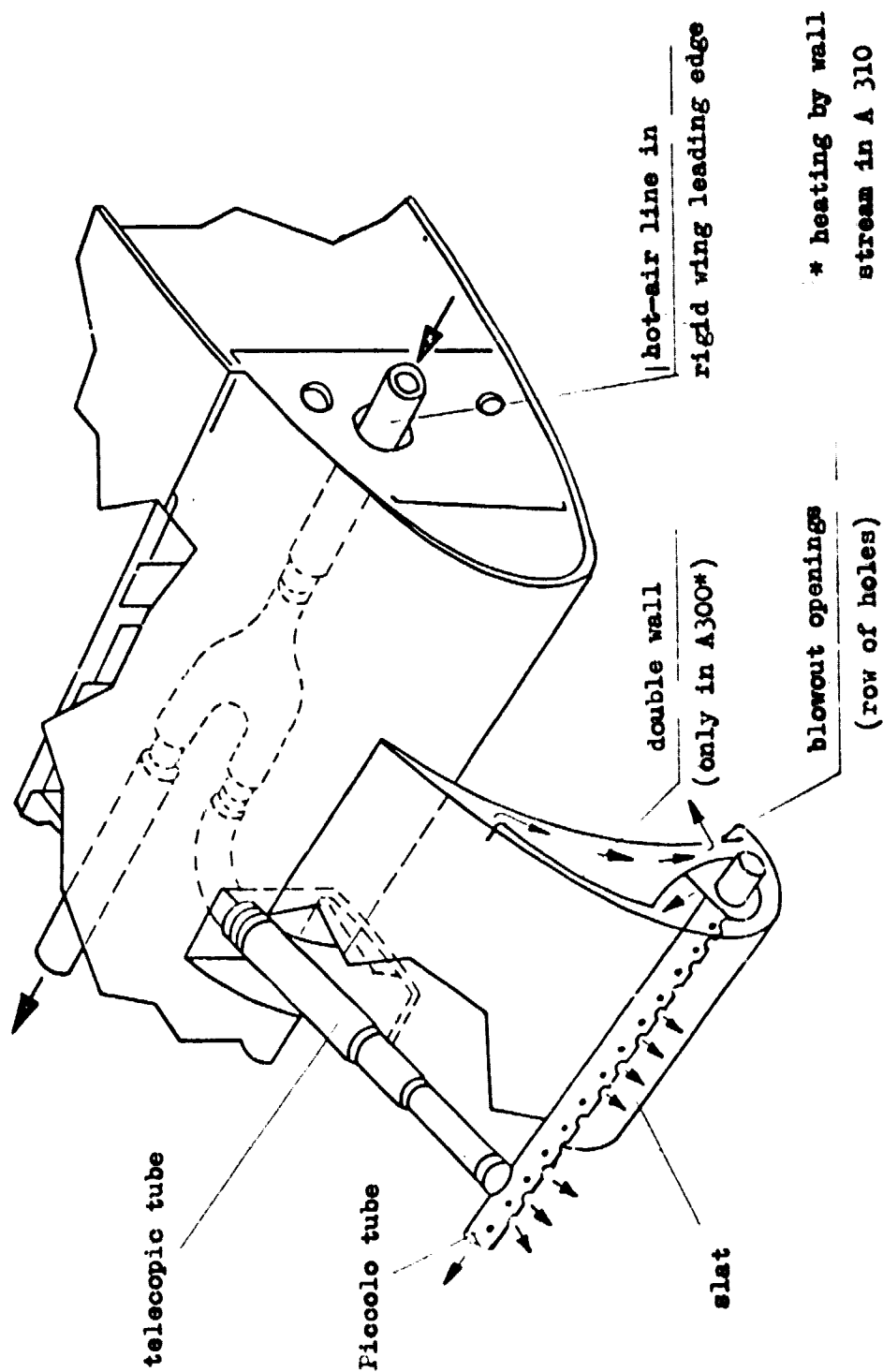


Figure 5 Principle of the hot-air distribution along the leading edge of the wing

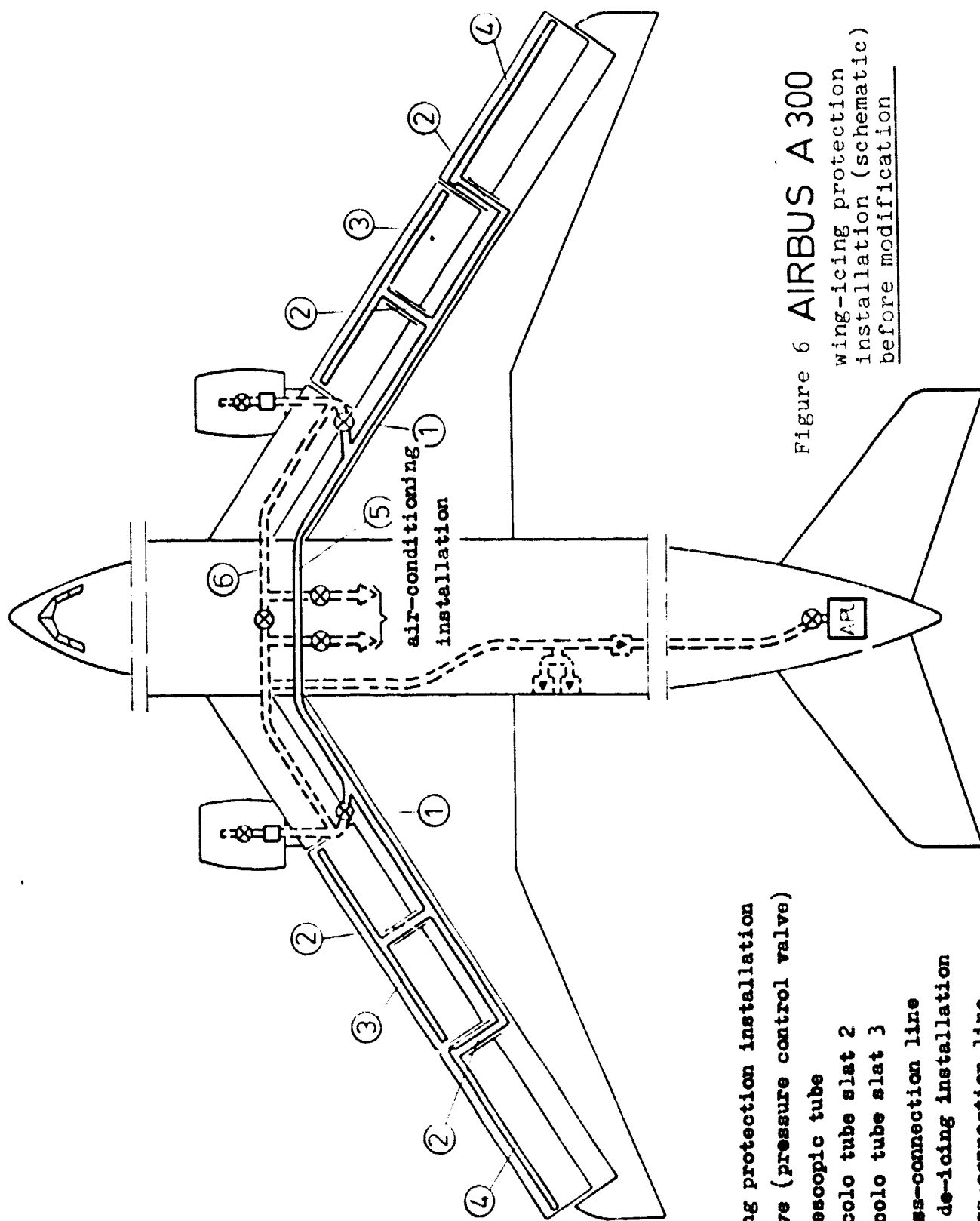
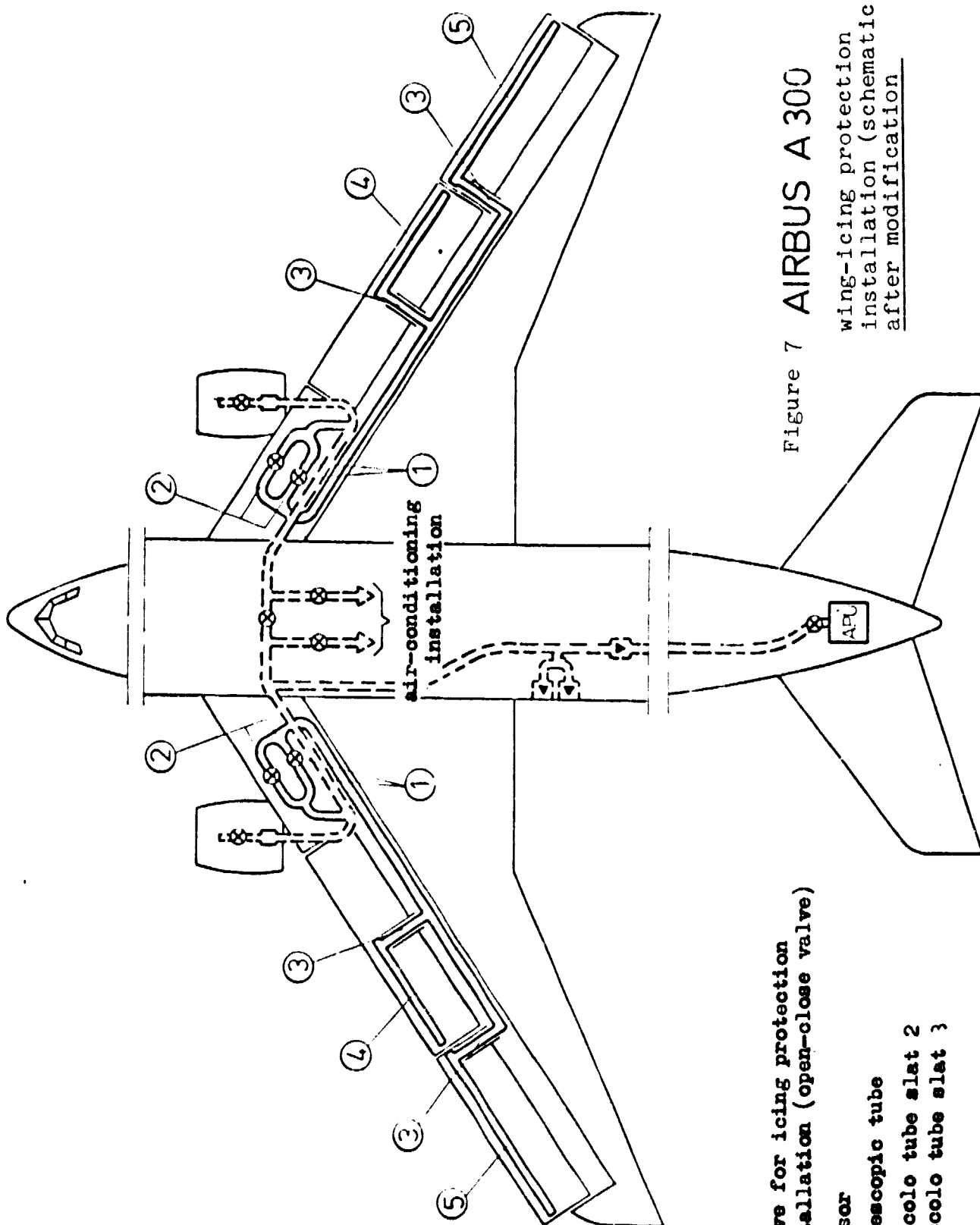


Figure 6 AIRBUS A 300  
wing-icing protection  
installation (schematic)  
before modification

- ① icing protection installation valve (pressure control valve)
- ② telescopic tube
- ③ Piccolo tube slat 2
- ④ Piccolo tube slat 3
- ⑤ cross-connection line for de-icing installation
- ⑥ cross-connection line for pneumatic system



- ① valve for icing protection installation (open-close valve)
- ② sensor
- ③ telescopic tube
- ④ Piccolo tube slat 2
- ⑤ Piccolo tube slat 3

Figure 7 AIRBUS A 300  
wing-icing protection  
installation (schematic)  
after modification



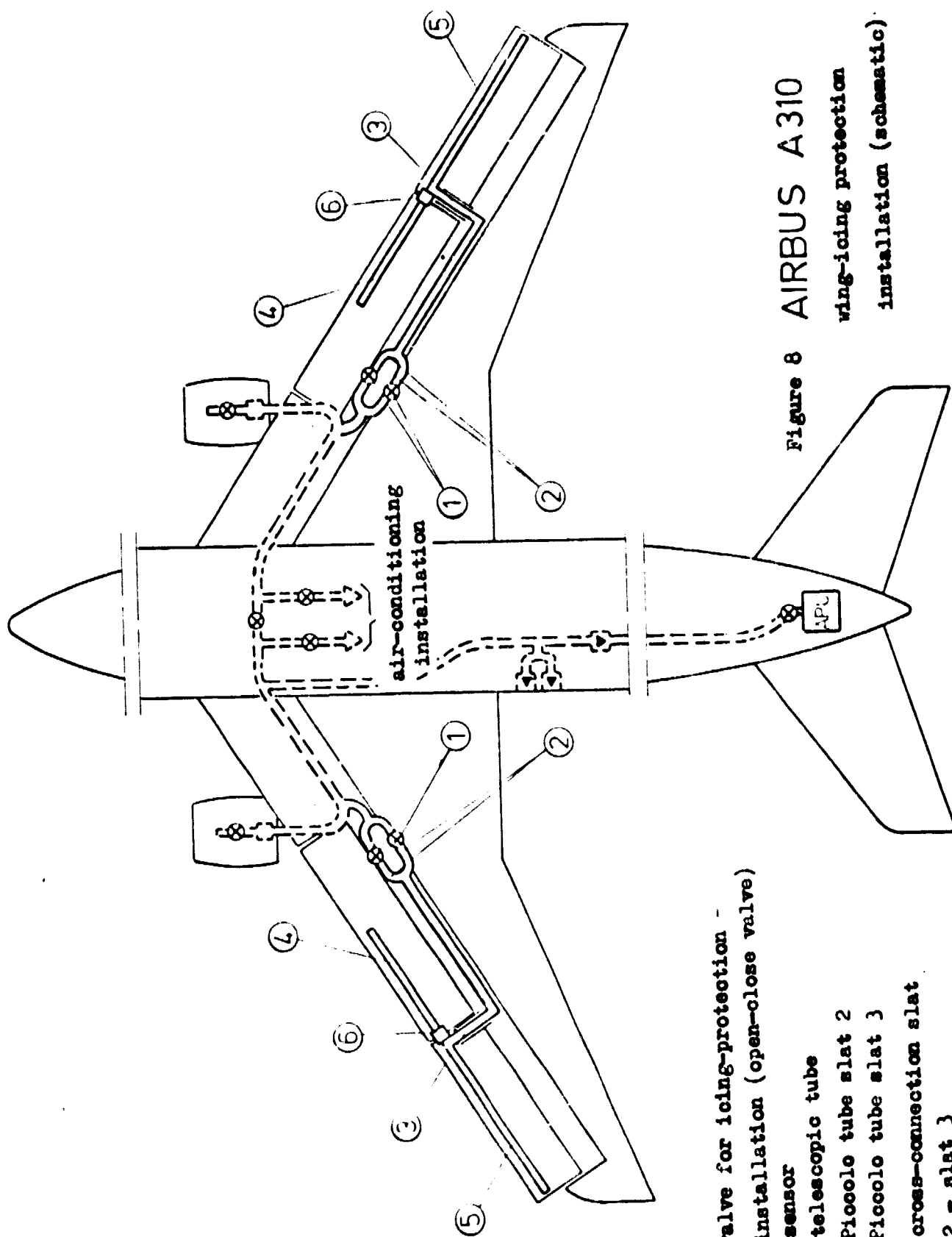


Figure 8 AIRBUS A310  
wing-icing protection  
installation (schematic)

- ① valve for icing-protection -  
installation (open-close valve)
- ② sensor
- ③ telescopic tube
- ④ Piccolo tube slat 2
- ⑤ Piccolo tube slat 3
- ⑥ cross-connection slat
- 2 - slat 3

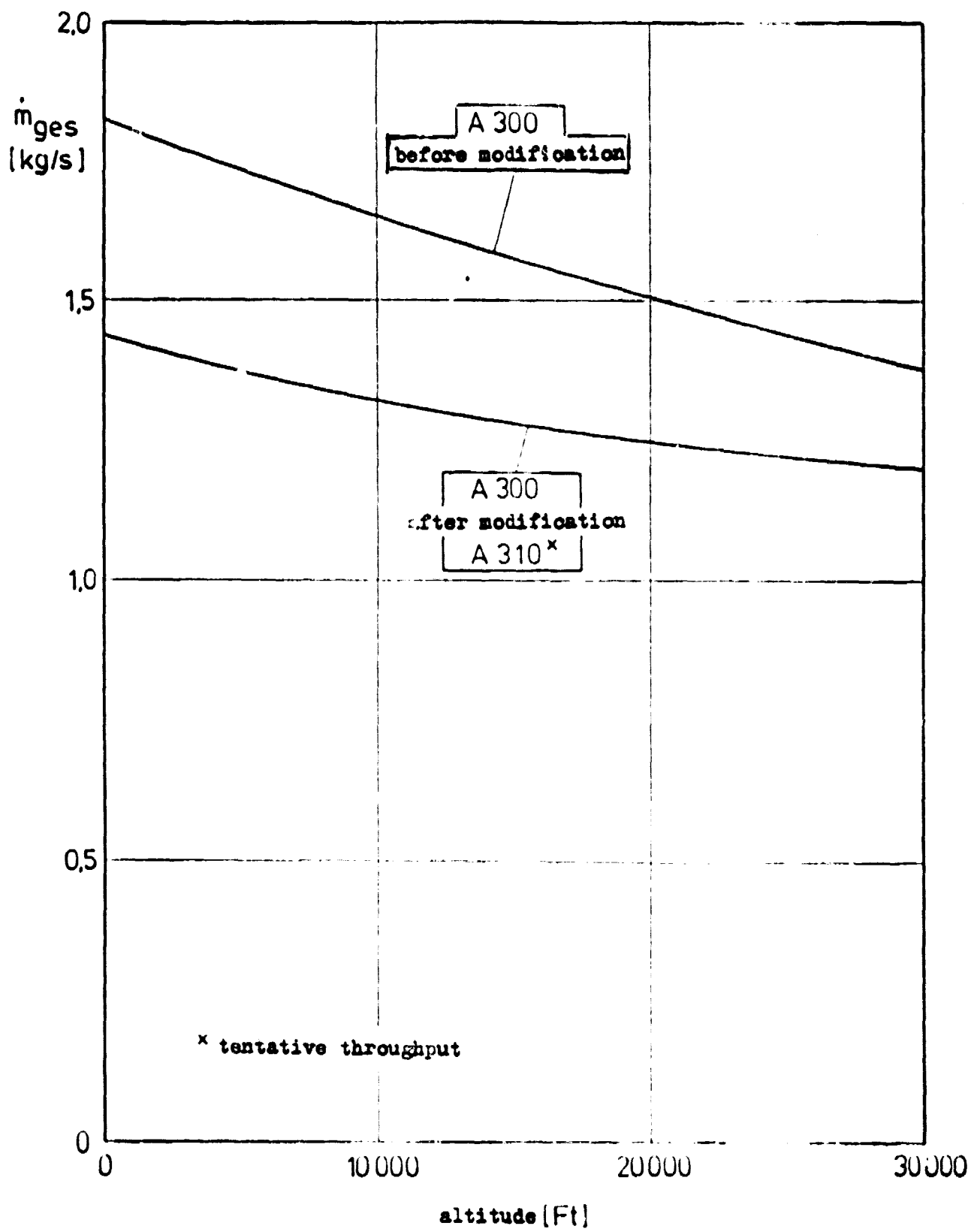


Figure 9 Total hot-air throughput of the wing icing-protection installation

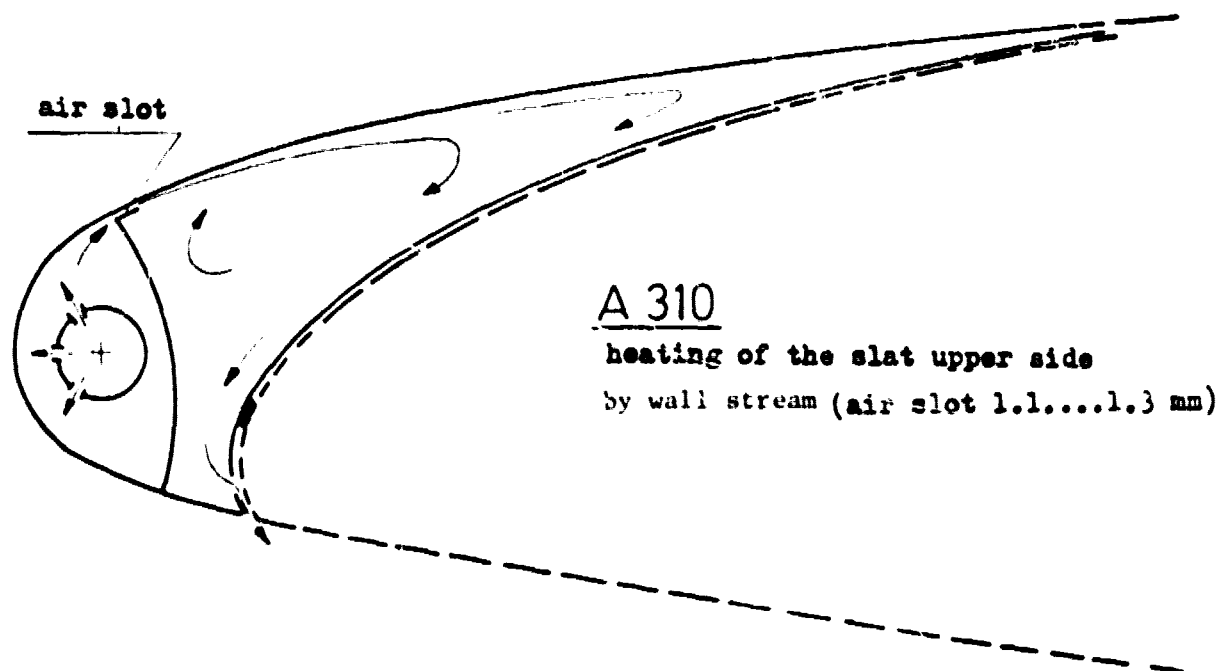
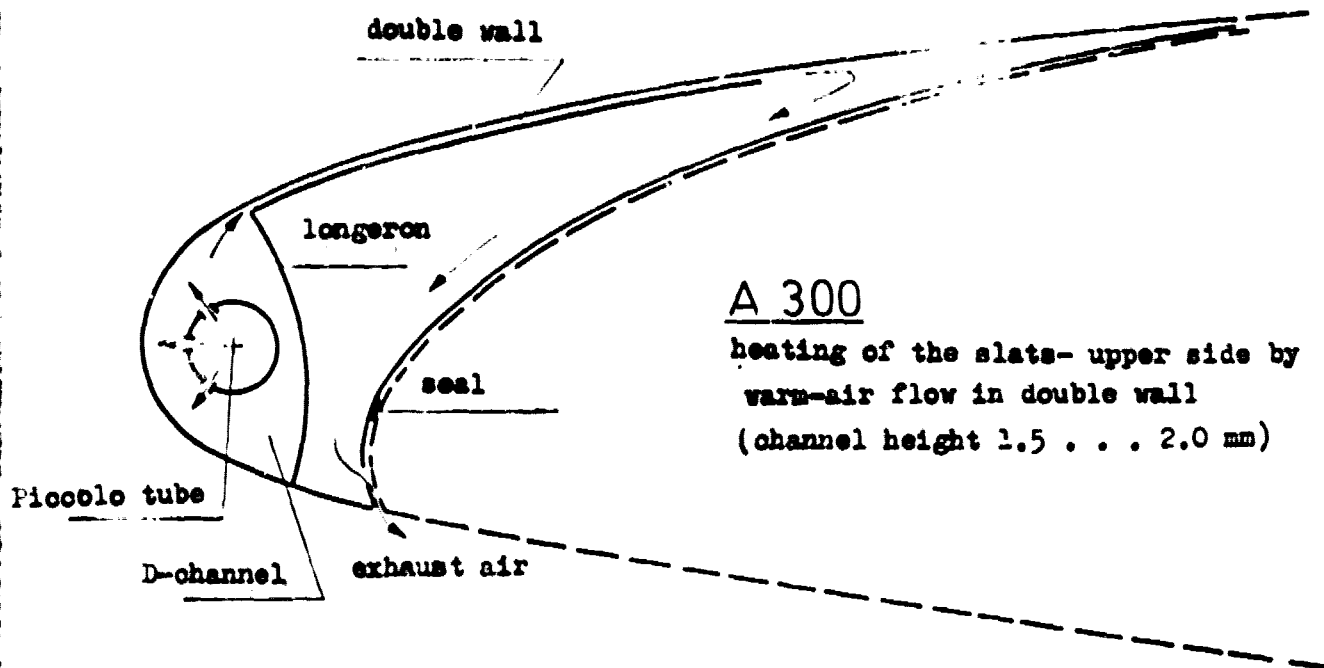


Figure 10 Warm-air passage in slat (schematic)

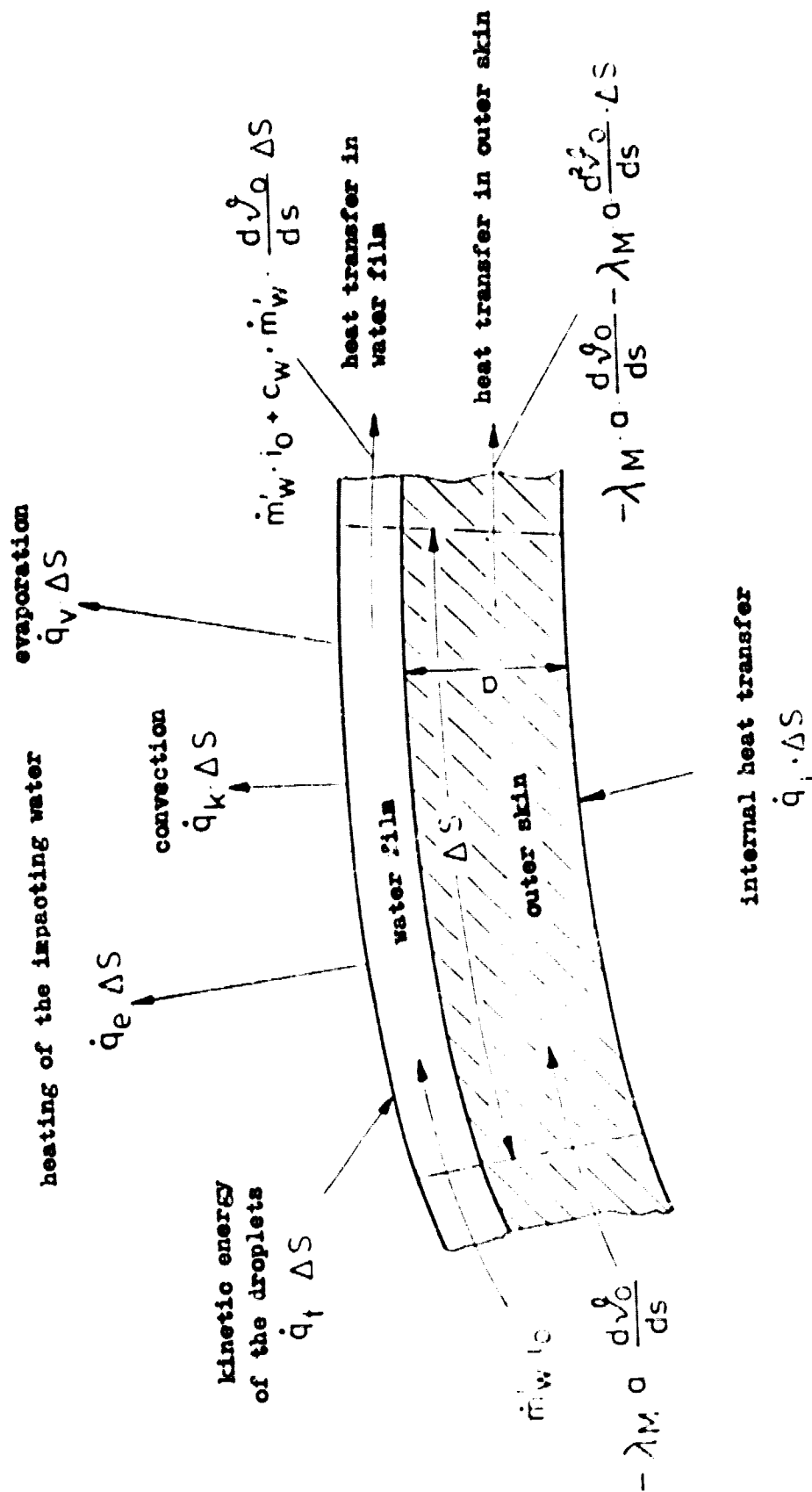


Figure 11 Heat balance on an element of a wet outer skin  
(surface temperature  $> 0^\circ\text{C}$ )

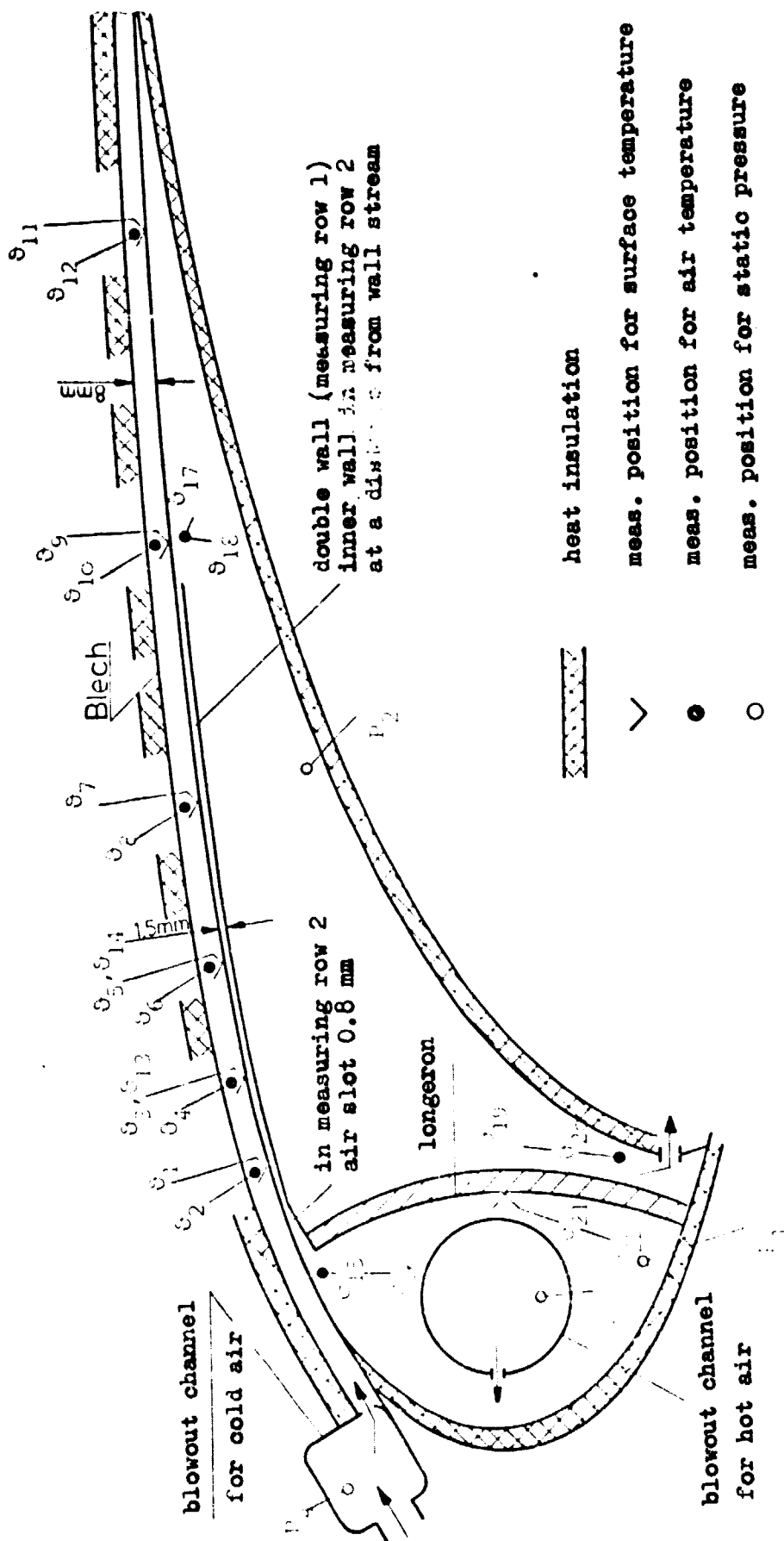


Figure 12 Model of A 300 slat for determining the internal heat transfer at the upper side of the slat (with and without double wall)

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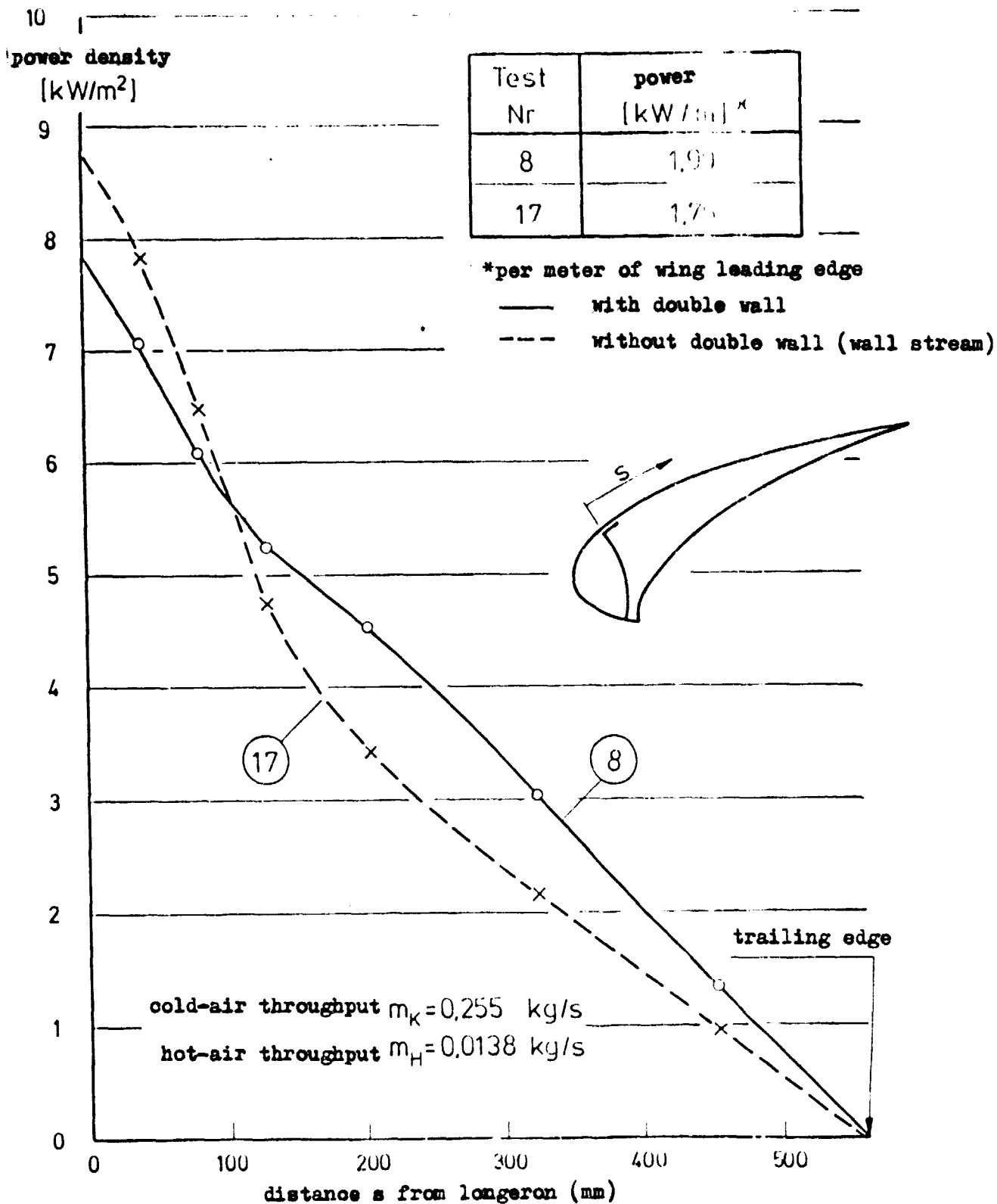


Figure 13 Power density at the slat upper side  
(typical result from laboratory test)

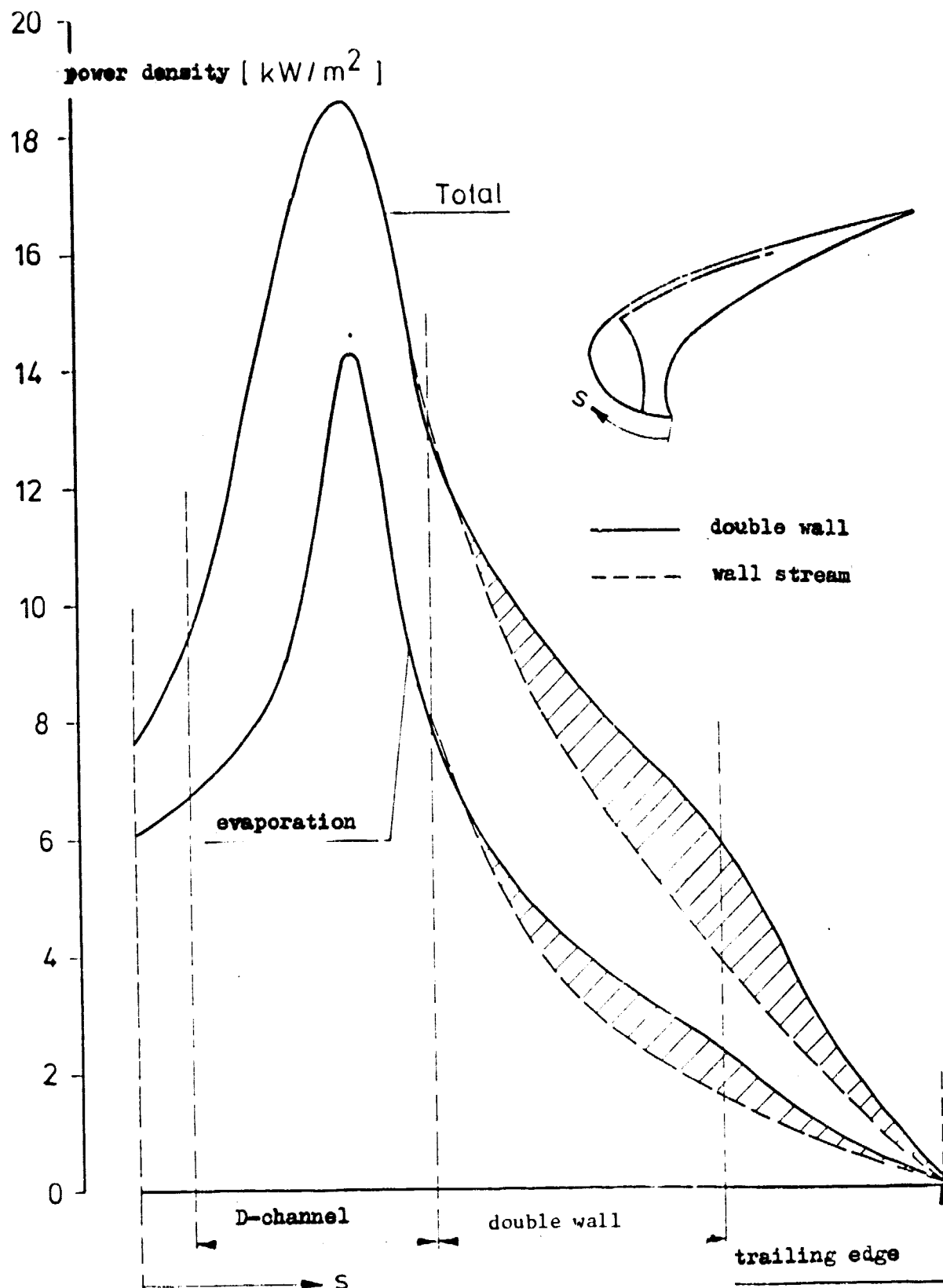


Figure 14 Power density at the A 310 slat (idle under continuous icing conditions)