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LAMINAR LEADING EDGES: MANUFACTURING, CONTAMINATION, AND OPERATIONAL ASPECTS – RESULTS FROM THE GERMAN RAWID PROGRAMME

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Abstract. *RaWid was the German national technology programme on transonic aerodynamics and supporting technologies, lasting from 1995 to 1998.*

One of the main topics was laminar wing development. Besides aerodynamic design work, many operational aspects were investigated. A manufacturing concept was developed to be applied to operational laminar wings and empennages. It was built in a large scale manufacturing demonstrator with the aerodynamic shape of a 1,5 m section of the A320 fin nose. Tolerances in shape and roughness fulfilled all requirements. The construction can easily be adapted to varying stiffness and strength requirements. Weight and manufacturing costs are comparable to common nose designs. The mock-up to be designed in ALTTA is based on this manufacturing principle.

Another critical point is contamination of suction surfaces. Several tests were performed to investigate perforated titanium suction surfaces at realistic operational conditions:

- a one year flight test with a suction plate in the stagnation area of the Airbus "Beluga"
- a one year test of several suction plates in a ground test near the airport
- a one year test of a working suction ground test installation at all weather conditions.

No critical results were found. There is no long term suction degradation visible. Icing conditions and ground de-icing fluids used on airports did not pose severe problems. Some problems detected require only respection of weak design constraints.

INTRODUCTION

RaWid (a German abbreviation for Cruise Drag Reduction) was the German national technology programme on transonic aerodynamics, lasting from 1995 to 1998. It delt with aerodynamic technologies and with technologies in other disciplines supporting aerodynamic improvements, mainly structures and systems.

Laminarization is the most promising single technology to improve the performance of modern transport aircraft. Therefore, one of the main topics in this programme was laminar wing development. Besides aerodynamic design work, some effort was spent to investigate many operational aspects and to develop a manufacturing concept which can be applied to operational laminar wings and empennages.

Oriented towards the requirements of a very large transport aircraft called MEGALINER, design studies were peformed for wing suction noses. In a space allocation study, the constraints for the installation of an operational suction system were incorporated as well as the structural constraints and the installation of Krueger high lift flaps.

In cooperation with BIAS, an institute at the Bremen University, a laser beam welding and forming method was developed to join small titanium stringers with titanium suction surfaces. Afterwards, the suction structure including the suction chambers was manufactured by pure cold forming and joining processes. In order to validate the concept and to compare it with in-house data, a large scale demonstrator was built having the aerodynamic shape of a 1,5 m section of the A320 fin nose. It fulfilled all requirements. The mock-up to be designed in ALTTA is based on this manufacturing concept.

Laminar flow is very sensitive to external disturbances. Therefore several tests were performed to check contamination of perforated titanium suction surfaces at realistic operational conditions:

- a one year flight test was performed with a suction plate in the stagnation area of the Airbus A300-600 STA "Beluga" to check long time degradation, mainly by insects
- a one year test of several suction plates placed at different orientations in a ground test rack near the airport, mainly to check long time degradation do tue environmental factors like dust, durty rain, air mixed with exhaust gases etc.
- a one year test of a working suction ground test installation near the airport at all weather conditions, mainly to check long time performance of suction systems at rainy weather, during winter periods with snow, ice and de-icing fluids and to check the system capabilities for de-icing and the removal of water in the perforation holes.

No critical results were found. There is no long term suction degradation visible. Icing conditions and ground de-icing fluids used on airports did not pose severe problems. Some small problems detected require only proper respection of weak design constraints.

INTEGRATED DESIGN OF A WING SUCTION NOSE

In the German national technology programme RaWid one important topic was the investigation of a laminar wing for a very large transport aircraft, similar to the planned A3XX; in research studies the generic type of aircraft was called MEGALINER. Besides pure aerodynamic studies and first wing design studies, it was checked, if space allocation for operational systems and structural requirements can be fulfilled. Based on the experiences of European programmes like ELFIN and the first experiences in the A320 laminar fin programme, aerodynamic requirements were formulated and the requirements for operational suction systems and structural design were composed.

High lift system

First major task was integration of the suction system and structure with a high lift system. As a first approach, suction was only respected for the upper side of the wing which provides about 70% of the drag reduction for a hybrid laminar flow wing. On the lower side of the nose, a Krueger flap system was installed for high lift purposes and for protection of the suction nose against insect contamination during low level flight (see figure 1):

- The Krueger flap can be positioned in a lower position providing maximum lift capability. This position will only be available at clean air conditions, i.e. during weather with no or only very few insects, e.g. during winter or rain.
- Insect contamination must be expected during warm seasons at all altitudes below cloud level (i.e. the dry convection zone). Then, the Krueger flap must be used in a higher position in order to shield the suction nose against insects. So, insects will either be collected by the Krueger flap or touch the fixed leading edge at such a low angle that they are deflected and do not stick to the surface. But maximum lift is slightly reduced at this high Krueger position.

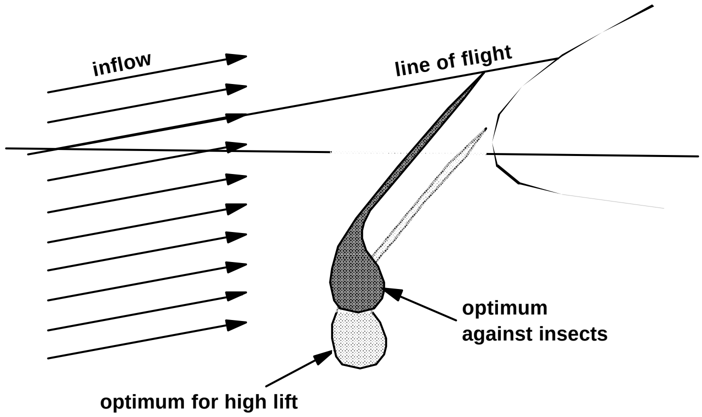


Figure 1: Krueger flap for insect protection

Two types of Krueger flaps were investigated: a small one consisting of only one piece, and a larger folded Krueger flap. The latter provides comparable performances to usual slat systems. Space allocation respected for the larger folded Krueger flap.

Structural and systems constraints

Based on first experiences with the A320 laminar fin design and first structural wing investigations, the thickness of the suction skin with the supporting sandwich structure was defined. Those assumptions were later on confirmed by the manufacturing concept described below.

System engineering investigated the systems required for a wing suction system. One result was the volume needed for the collection chambers and the piping in the wing. Combining the collection chambers and the pipes into collection pipes seemed preferable. It would save space and provide a structure which is lighter and which can easily be adapted to different stiffness and strength requirements.

Space allocation study

A space allocation study was performed for the relatively thin MEGALINER hybrid laminar wing nose. It consisted of several spanwise nose segments, each about 2.5 m long. Suction was used on the upper side of the forward 20% of the wing, ahead of the front spar.

On the lower side, the folded Krueger flap was installed including its actuation mechanism.

Although the integrated collection pipes were preferable, for this space allocation study separated collection chambers and pipes were respected to solve the more space consuming problem.

The space available for all those installations became strongly limited in the thin outer part of the wing. Eventually, a solution was developed for the complete wing which served as a first step for detailed design studies. In figure 2, a cut through an outer part of the wing nose is given showing space allocation for the suction structure, suction chambers and piping in the front und upper part of the nose, whereas the lower part is occupied by the Krueger flap system.

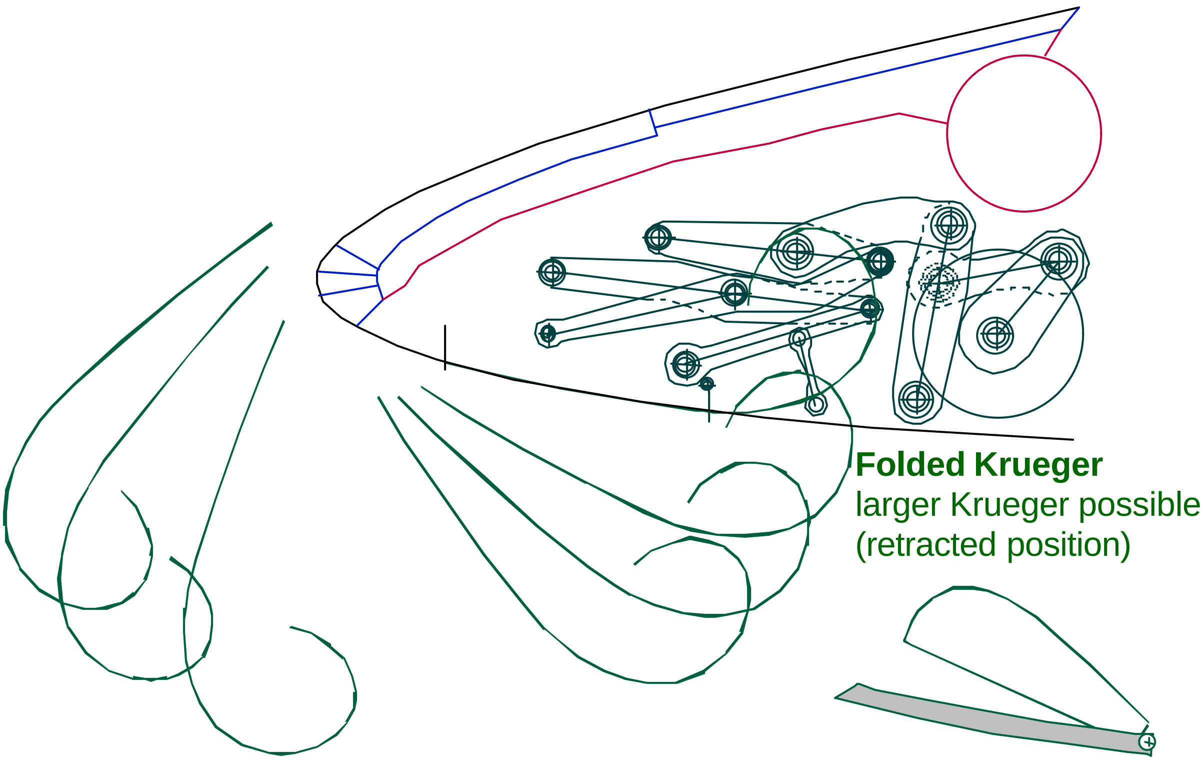
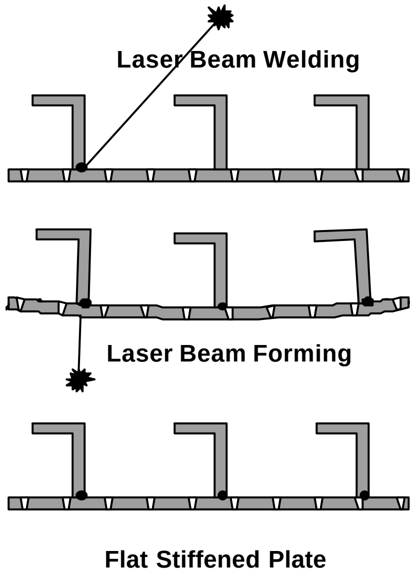


Figure 2: Space allocation study of a hybrid laminar wing nose for a MEGALINER

RAWID MANUFACTURING CONCEPT FOR SUCTION NOSES

Joining of the perforated skin an stringers

In cooperation with BIAS, an institute at the Bremen University, a laser beam welding method was developed to join small titanium stringers with perforated titanium suction surfaces. Many tests and manufacturing concepts were investigated. Eventually, the flat perforated titanium skin was joined with the small canted stringers by a laser beam welding process. After welding, the skin became bended at the welding line. To reduce the fold, laser forming was applied from the opposite direction. It was possible to completely remove the fold; only a minute local double wave of less than 10 µm height remained. Eventually, it was possible to manufacture flat stiffened plates of realistic size with a local surface waviness below 10 µm everywhere (figure 3).



Figur 3: Joining skin with stringers

The stringers were placed according to the A320 laminar fin design in the front part of the nose and at constant distances in the rear part, where honeycomb stiffeners were used for the A320 laminar fin. All stringers were placed at constant relative coordinates along generating lines of the conical A320 fin nose. After laser beam welding and forming, a perfect flat stiffened perforated plate was available.

Alternatively, special brazing procedures may be applied instead of laser beam welding.

Building of the large scale manufacturing demonstrator by cold processes

The flat, in one direction stiffened suction plate was formed by a special cold forming process to generate the aerodynamic shape. Using a winding mechanism, the stiffened skin was wraped around form ribs and provisionally fixed to the ribs. When the final shape was achieved, the plate with the mechanism was placed and fixed in a mold.

Now the inner perforated skin for throttling and stiffening was joined to the canted stringers of the outer skin. For joining, each technique without strong thermal loads may be applied, e.g. (blind) rivets, spot welding; in the demonstrator, many skrews were applied due to administrative reasons. At the borders of collection chambers, a sealing must be applied before joining.

Afterwards, ribs for stiffening and shape conservation, and collection chambers were installed and fixed by the same means as the inner skin. Where required, sealing was applied prior to joining.

A large scale demonstrator for this manufacturing process was built. It has the aerodynamic shape of a 1,5 m section of the A320 fin nose (figure 4). The interior installation is only for demonstration purposes and not yet designed for application. Tolerances in shape and roughness were checked and fulfilled everywhere the requirements. The construction can easily be applied to varying stiffness and strength requirements. Weight and manufacturing costs are acceptable and are -not respecting for the special suction installations- comparable to usual nose designs.

The mock-up to be designed in ALTTA is based on this manufacturing principle.

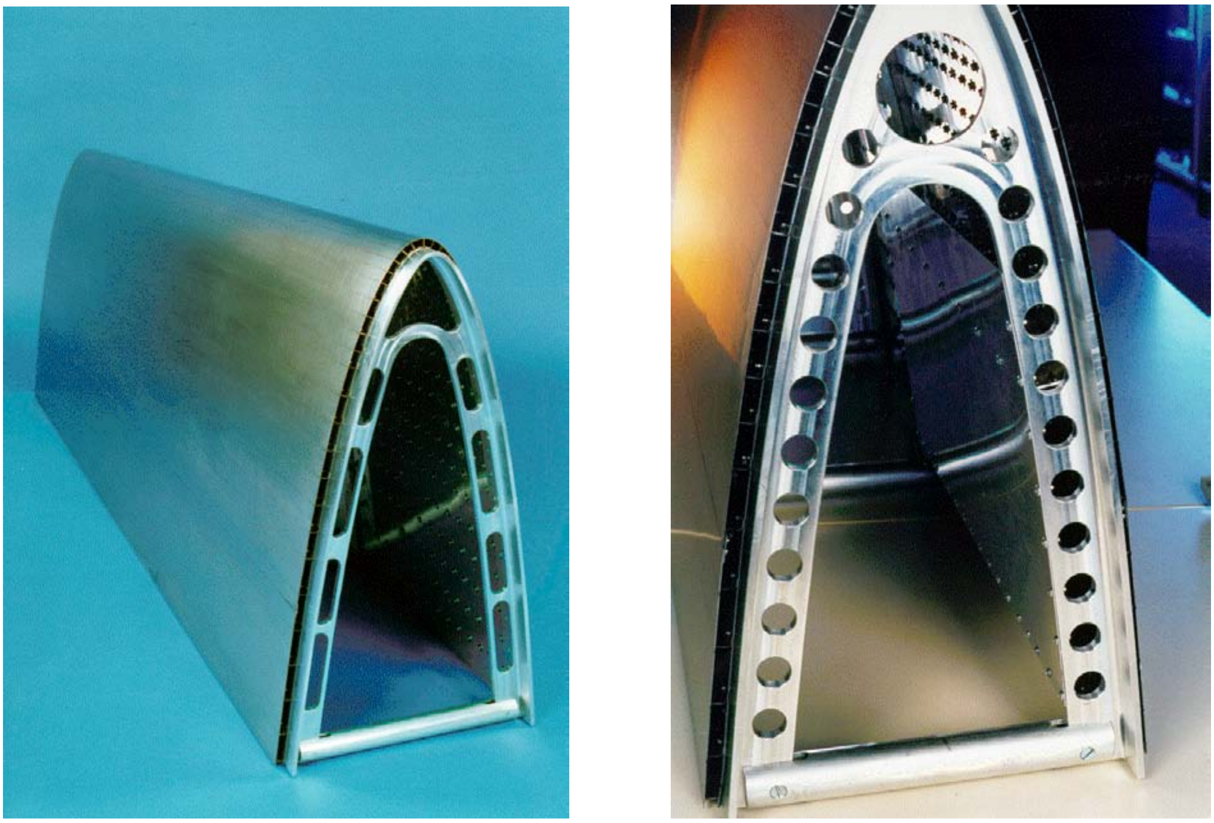


Figure 4: RaWid manufacturing concept for suction noses

CONTAMINATION TESTS

Contamination of suction surfaces is a critical point, for which only insufficient experience is available. The perforated surfaces are prone to insect contamination, mainly during flight at low levels in the thermal convection zone. When staying on ground, the suction holes may be closed by rain, dew or white frost in the morning, or they may be deteriorated by dust or oil vapour (kerosene). Especially aircraft conserving measures like ground de-icing fluids or even aircraft cleaning may block the suction holes. Several tests were performed to check perforated titanium suction surfaces over a long period at realistic operational conditions.

"Beluga" flight tests

There are only insufficient data available on operational contamination of perforated suction surfaces. Therefore a low cost possibility for such a test was investigated. Requirements were:

- A test plate of perforated titanium should be installed on an aircraft during an operational period of at least one year to cover all seasons.
- The selected test aircraft should operate in different climatic zones.
- The test plate should be installed in an area, where insect contamination occurs, i.e. in the stagnation area with an high angle against the flight direction.
- The plate should be installed so, that the air can flow through the suction holes from the forward ("outer") side to the rearward ("inner") side. This should model the suction process.
- In order to monitor the possible degradation, two identical test specimen should be used which were to be exchanged every month on the test aircraft. After exchanging the test specimen, they were to be checked in the lab:
  . check of porosity at several specified locations (throttling test)
  . optical investigation via a microscope.
- It was decided to clean one of those test specimen after investigation in the lab by ultrasonic cleaning (every second month). The other test specimen was never to be cleaned in the lab, but should only follow the usual operational procedures on the aircraft including the standard aircraft cleaning.

At first a suited passenger aircraft was looked for. It turned out to be difficult and expensive. Even for usual freighter aircraft it was difficult an at least expensive to fulfill all requirements. Eventually, the Airbus A300-600 STA "Beluga" was selected: In the forward part of the fuselage above the cockpit there is a removable inspection plate at a position which fulfilled all requirements. It is still located in the external overpressure area (stagnation area) whereas on the inner side there is only the static pressure, because the "Beluga" is not pressurized in this area. Pressure difference from outside to inside resembles the pressure drop over suction panels. Therefore, instead of this plate a perforated titanium sheet of the same size and shape was installed. It was exchanged with a second identical one every month.

"Beluga no. 3" was selected, because this aircraft is used for world wide special transports covering many climatic zones. Figure 5 shows "Beluga no. 3" on an American airport with the perforated plate installed; during this tour it even visited the Boeing airfield in Seattle for an international air cargo conference.

Surprisingly, not any persistent environmental degradation was found on any of the two plates over the whole period of more than a year. The only persistent degradation found was some aircraft colour which was mistakenly applied on the corner of one of the plates in the paint shop. This colour reduced perforation significantly and so locally increased throttling. Sometimes there were single mosquitos on a plate collected at the end of the last flight; but during rain or in ice clouds, they were completely removed. Also, no significant difference was found between the lab cleaned plate and the uncleaned (lab) plate. (The uncleaned plate showed even less variation, but within measurement tolerance.) The suction holes did not collect dust particles, neither during rain nor aircraft cleaning procedures. Water collected during rain or dew and white frost did not stay in the holes for long time.

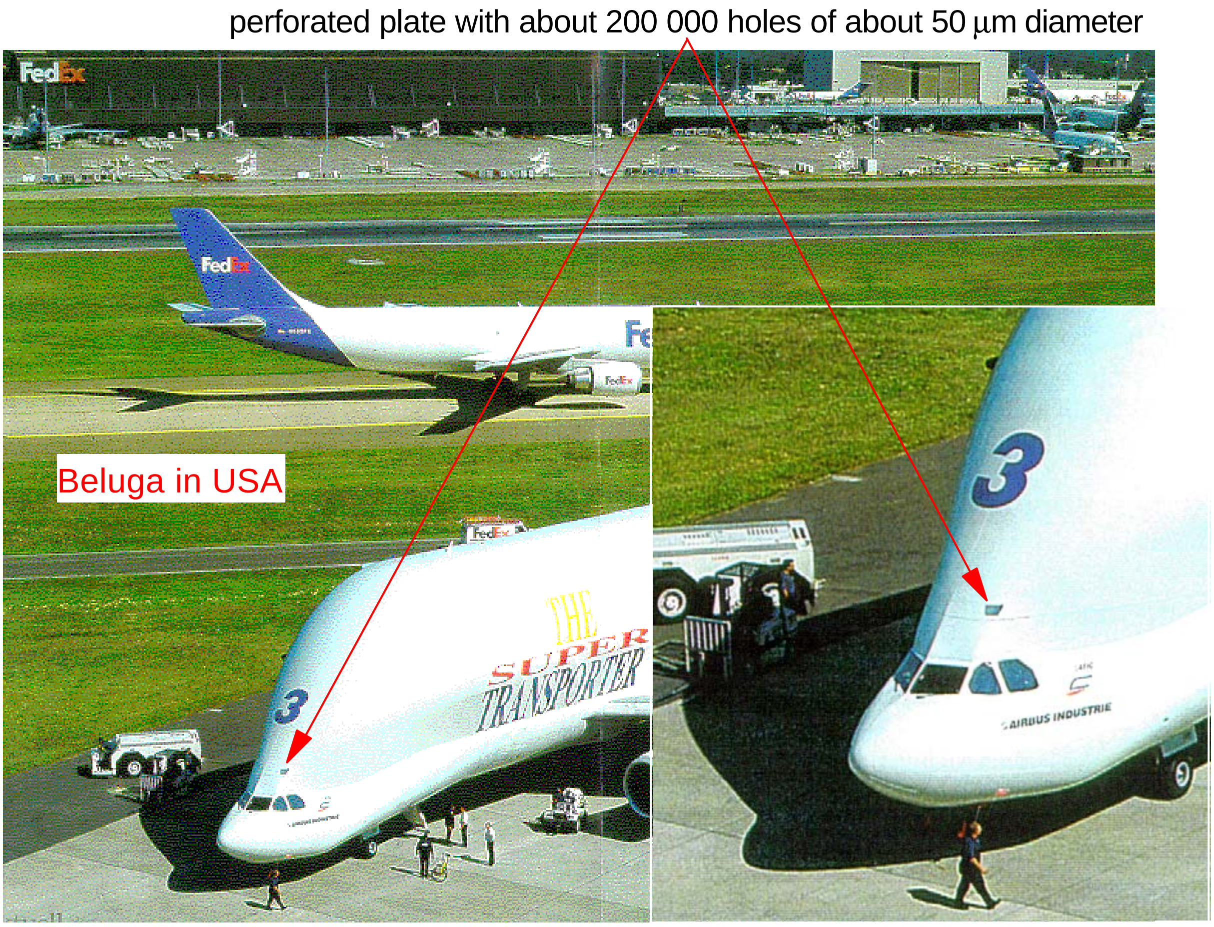


Figure 5: "Beluga no. 3" with a perforated test plate

Ground contamination tests

Aircraft often stay on ground for some time: during night, for inspection etc. During this time, environmental particles are collected on the aircraft's surface: rain, dust, dew or white frost in the early morning or air with oil vapour (kerosene). During this time, the aircraft usually is off-power so that blowing out air through the holes may not be applicable for avoiding contamination.

To check the sensitivity of suction panels against environmental degradation, a test rack was installed at the border of the Bremen airport. Different test specimen (size 20x30 cm²) were placed side by side in the rack, each of different surface or orientation (conical holes with the large diameter to the front side or with the small diameter to the front side). In a row, all test specimen were similar, but installed with different angles against the horizon: 90°, 45° and 0° (see figure 6). The test specimen were placed in the rack for one year and regularly checked in the rack by optical inspection and throttling tests.

For nearly all test plates no degradation was found. Only for the test plates at low inclination angles (0° and 45°) which have the conical hole orientation with the larger diameter up and the lower diameter down, many holes became closed during spring time: The small dust particles of flowers were collected in the small hole funnels and were never removed by rain; whereas in all other cases the natural movement of air and rain cleaned the conical holes.

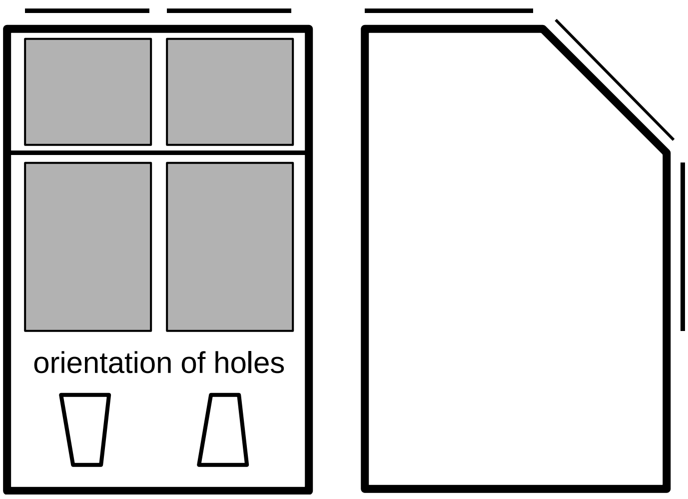


Figure 6: Ground test rack for perforated plates

Ground suction tests

When an aircraft stays on the ground, often for several hours, it can be covered by snow or the suction holes my be closed by dew, white frost or rain. To remove snow or avoid icing during ground time, ground de-icing fluid must be applied; it covers the whole aircraft including the sensitive nose region with the suction area. To check the sensitivity of a suction system against environmental influences during aircraft ground times, and to test the measures envisaged to overcome difficulties, a ground test station was installed on the company's airport at Hamburg-Finkenwerder (figure 7).

Two consecutive suction chambers of semicircle shape were installed with the suction circle on the upper side. At the front end of the first chamber the main tapping is installed. It is possible to suck air at usual suction levels, to blow cold and hot air for cleaning or de-icing and to stay at idle conditions. Measurement equipment monitored the environmental conditions (temperature, humidity, rain/ snow, wind, dust), the system parameters of the suction, blowing and heating equipment, and the conditions of the suction chambers at several positions (pressure distribution, temperature). An automatic test procedure was installed to simulate suction during


Figure 7: Ground suction test

flight time, blowing during ground roll, take-off and landing and down times in between. Some hours per day were down time. When rain was detected during operational hours, the system changed from suction to blowing (if suction mode was active). Additionally, special investigations were performed, when natural weather conditions were suited: white frost, snow, icing conditions and application of de-icing fluid.

During standard tests, no significant long time degradation of the test equipment occured. This was monitored mainly by the pressure drop in the suction chambers. But during long dry periods, atmospheric dust which was sucked in, seemed to increase pressure losses in the suction holes. But the next rain cleaned the holes (figure 8) to original pressure loss values. In flight, suction will only be applied at cruise altitudes, where clean air prevails. After a rain, there was no problem to blow the remaining water out of the holes. But the suction chambers must have a water drainage.

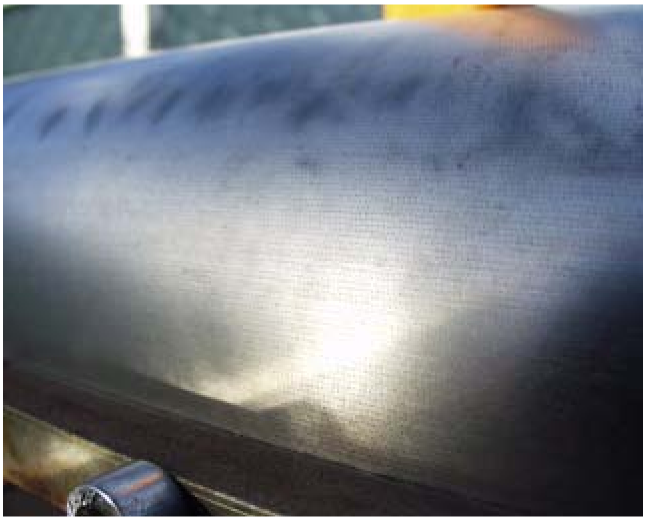


Figure 8: Titanium skin with holes (test chamber)

After dew, white frost or snow, the system can easily be cleaned by blowing, if necessary with hot air. No additionl pressure loss remained.

Because no natural ice occured, at cold weather a water mist was applied which froze on the suction surface. It could easily be removed by simple blowing. Strong icing conditions, which may occur with white frost and ice at very low temperatures, could not yet be simulated. According to our experience and the measures planned, no problem is expected.

Strongest doubts were on performance with de-icing fluid, because it is a visco-elastic fluid of tough consistency to stay longer on the aircraft's surface during ground time. To test it, standard de-icing fluid was applied on the suction surfaces with a standard device from the airport; it was sprayed from a standard distance of about 2 m. During spraying, the blowing mode with cold air was active. Within half an hour nearly all the de-icing fluid disappeared; pressure drop in the suction chamber returned to nearly identical values as before the application. It is expected, that during take-off the de-icing fluid will even faster disappear due to its visco-elastic properties.

Contamination summary

No critical results were found. There is no long term suction degradation visible. Icing conditions and ground deicing fluids used on airports did not pose severe problems. Some problems detected require only respection of weak design constraints.

An open problem is still short term contamination of unprotected surfaces, especially by insects. But in many cases the insects will be removed during the flight, e.g. by rain, ice clouds or dust particles.

For the remaining cases it should be distinguished between uncritical cases, when performance degradation does not influence the aircraft's mission, and critical cases, when the aircraft's mission cannot be fulfilled due to degraded performance.

- The first is for cases when laminarization increases performance only to an amount well below the mission fuel reserves, e.g. for fin laminarization. Special protection measures are not mandatory, but they will improve the systems reliability and its benefit for the customer.
- The latter concerns large laminar parts like the wings. Performance improvement for the complete laminar wings is higher than mission reserves. A total loss of laminar flow at the beginning of a flight will not allow to reach the destination. This can even be worse than an OEI (one engine inoperative) case. If this should be very rare, it can be handled like an OEI-case, especially because insect contamination is to be expected only during take-off or landing phases, but not during cruise; but then it must be detected in order to allow the pilot to react on it.

  In any case, it would be preferable to avoid such a total loss of laminarization, e.g. by shielding the wing's nose against insects with a Krueger flap, as proposed above. Probably, the airlines will only accept a laminar wing, when total loss of laminar performance is avoided or only extremely rare.

CONCLUSIONS

Laminarization of a transport aircraft's aerodynamic surfaces is the technology in sight which provides the highest performance improvement. In several studies within the German national technology programme RaWid it was demonstrated, that no show stoppers exist for this technology.

For the very difficult task of a MEGALINER, it was demonstrated, that systems, structure and a high lift system can be combined in a suction nose in front of the wing box, even in the outer wing with its strong space limitations. For aircraft with (relatively) thicker wings, it will even be easier.

So far, no structural concept was proposed which fulfilled all requirements for a suction nose: aerodynamic smoothness, impact strength, low weight, stiffness adapted to the load carrying box etc. Therefore a new concept was developed meeting the requirements. A flat suction panel is joined with stiffeners by laser beam welding and laser beam forming. The aerodynamic shape is generated by a cold forming process; the interior structure and installations are joined by classical cold joining processes including sealing. This concept was proven by a large scale manufacturing demonstrator. The ALTTA mock-up will be based on this concept.

Many concerns existed for the environmental degradation of suction surfaces. This was investigated in several special degradation tests. Not many degradations were found, not any was found which cannot be overcome by simple measures.

Now, as we do not see any more show stoppers, we should proceed with the development of this enabling technology. Next logical steps will be an operational flight test of a laminar fin and a first test with wing laminarization, preferably with a glove on a transonic transport. Both can be done in parallel. And then: which company will sell it ?

ACKNOWLEDGEMENT

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