SLI-RTM FAIRINGS FOR FAIRCHILD DORNIER DO 328 JET

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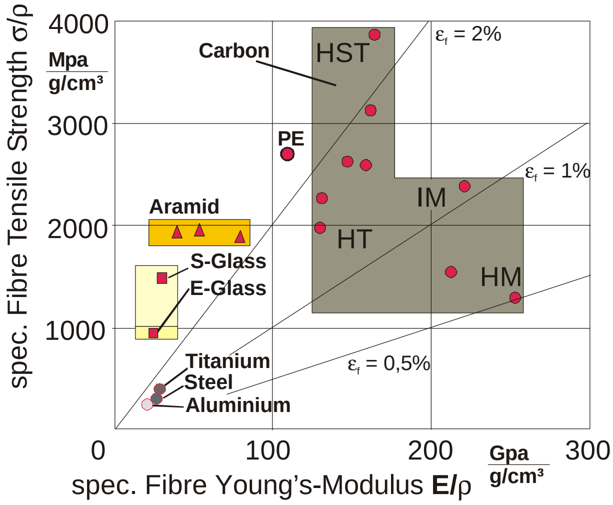
SUMMARY

A cost-optimised production method for high-quality fibre composite components developed at the DLR Institute of Structural Mechanics is presented here. The approach of the so-called Single Line Injection (SLI) method is to combine elements of established production methods with the goal of cost effectiveness at the best possible quality. The potential of this method is shown by an analysis of the first serial application which, in cooperation with Präzisionstechnik Gedern and Fairchild Dornier, was set up and approved of within a very short time period. The object of this presentation is the essential steps of the production process and experiences made during manufacture as well as the classification of the costs incurred. Finally, the SLI concept is compared with other manufacturing processes.

THE POTENTIAL OF COMPOSITE MATERIALS

Because of their many applications in aerospace, fibre composite materials are also being used in other industrial branches and, as a result, their significance is steadily increasing.



Carbon fibre

HST:	High Strain
IM:	Intermediate
HT:	High Tensile Strength
HM:	High Modulus

Glass fibre

S:	Strength
E:	Electric (standard fibre)

Polyethylene fibres

PE:	e.g. Dyneema

Fig. 1: Specific fibre Young's modulus and specific fibre tensile strength [ref. 1]

This development is primarily due to the outstanding lightweight construction potential of the fibre composite materials which is based on the high specific stiffness and strength of the reinforcement fibres. In addition, further advantages for concrete applications such as uncritical fatigue behaviour, constructable material properties, high resistance to corrosion and aggressive chemicals, free shape design, very good internal damping properties, or low thermal conduction can play decisive roles as well.

STATE OF THE ART

With the exception of filament winding structures, high-quality, continuous fibre-reinforced components are currently being industrially manufactured with the prepreg method. However, due to rising production costs, research on the so-called liquid resin infusion method (RTM, VARI etc.) has intensified lately since this method promises a significant reduction in manufacturing cost.

The Prepreg Autoclave Technology [ref. 2]

At present, the prepreg autoclave method is primarily being used for the manufacture of high-quality composite components since it provides a very high and reproducible component quality while requiring a moderate investment of tools. The high component quality is attained by compacting the prepregs, in the autoclave. Simple tools are required because only single-sided supporting tools are needed which have a flexible vacuum cover. However, prepregs are costly due to their specialised manufacturing process. In addition the lay-up process with prepreg is more complicated than with dry fibre material.

The Resin-Transfer-Moulding Method [ref. 2]

The Resin-Transfer-Moulding (RTM) method has become established in the past few years as an alternative to the Prepreg Autoclave technology. In this method, a cost-effective and non-impregnated fibre preform is placed in a massive mould to which a low-viscous resin system is injected under pressure. The considerably lower costs of the semi-finished product are advantageous here when the manufactured quantity warrants the enormous investment costs for the vacuum-tight, temperature-adjustable, pressure-loaded, and often very complex and heavy moulds. Since a compacting of the laminate which is even and expandable in all directions is not possible in massive RTM moulds, a reduction in the quality of the laminate and fibre content must be expected.

VARI / SCRIMP Technology

A promising subtype of the VARI (Vacuum Assisted Resin Infusion) technology is the SCRIMP method. In the SCRIMP (Seeman Composites Resin Infusion Moulding Process) method a flow aid is applied to the dry fibre perform that enables a quick distribution of the resin during infiltration. As opposed to RTM methods, the infusion and curing process take place at ambient pressure. In contrast to classical VARI methods, the infiltration of the resin takes place perpendicular to the flat fibre reinforcement. Normally, a single-sided mould is also used here which is sealed with a vacuum bag on the opposite side. Because of the very low fibre compacting as well as uncontrolled impregnation, the quality of the laminate is usually considerably lower than with the Prepreg Autoclave method.

THE SINGLE LINE INJECTION (SLI) METHOD [ref. 3]

Since the quality and economical manufacture of fibre composite components play decisive roles in their successful introduction into the market, a manufacturing process was developed at the Institute of Structural Mechanics with the goal of producing high-quality fibre composite components with the best possible laminate and surface quality in a cost-optimised production process. The process was to be optimised for the production of small series and prototype components with a quantity of up to 500 pieces per year since a great market potential is developing in the areas of aircraft, railway, and vehicle prototype construction.

The Principle of the SLI Method

The approach for the development of the SLI method essentially is to combine the advantages of the raw material of the liquid resin technology with the laminate quality of the Prepreg Autoclave technology.

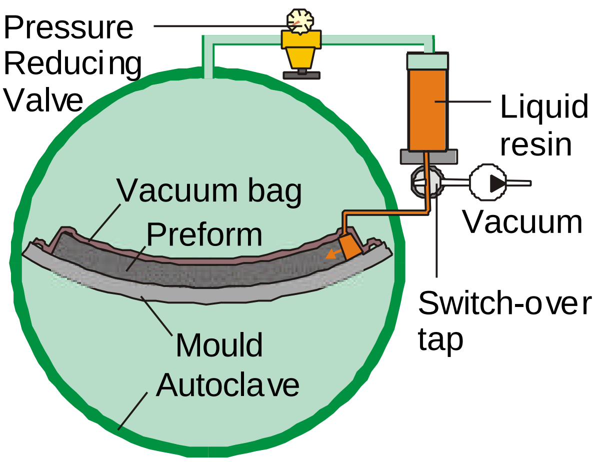


Fig. 2: Depiction of the SLI Method

The advantage of this method in comparison to the VARI method is that the resin is injected under pressure and that the laminate can be compacted by the autoclave pressure. The name of the method is an indication that the evacuation of the fibre preform as well as the injection of the resin system is carried out with the same line. This combination of injection / evacuation line can be arranged on the fibre preform in any arrangement to shorten the flow path and, with that, the injection time.

With the SLI method, it is possible to combine cost-effective and dry semi-finished fibre products such as fabrics, weaves, and warp knitted fabrics with the optimal matrix resin for each application. In addition to the standard epoxy resins, vinyl ester resin, and polyisocyanurats (Blendur), heat-resistant resins such as bismalimide, cyanate ester and even phenolic resins can be used. The excellent and void-free laminate quality achieved by the Autoclave Process leads to a superb component quality which almost reaches the status of a Class A surface.

Variation of the Fibre Volume Content

An additional characteristic of the SLI method is the possibility to directly influence the fibre content by means of the process parameters. This is possible because the flexible half of the mould enables the autoclave pressure to be in equilibrium with the inner resin pressure of the component and the restoring force of the fibre material. If the autoclave pressure is adjusted to be the same as the inner resin pressure, the fibre material can relax in the thickness direction and can support the impregnation due to greater permeability. If the component is completely impregnated, the autoclave pressing on the fibre material can be selectively increased by reducing the injection pressure until the desired fibre volume content of normally 60% is reached.

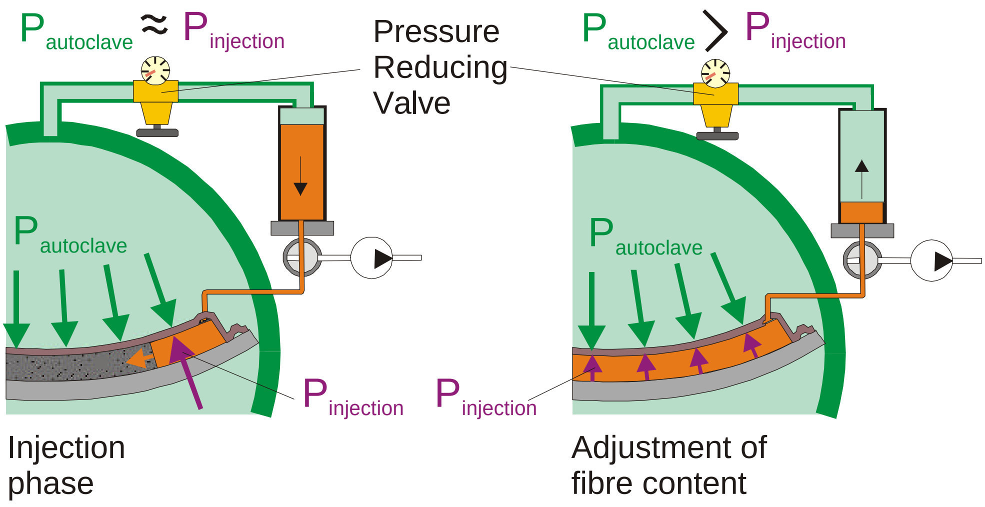


Fig. 3: Pressure distribution during injection and adjustment phase

MANUFACTURE OF CFRP FAIRINGS IN SLI TECHNOLOGY

In order to demonstrate the potential of the SLI technology, a production concept for complex and stringer-stiffened CFRP fairings of the Dornier Do 328 Jet engine pylon was developed, implemented, and given the necessary aerospace authorisation. In addition to relevant production aspects, a quality assurance concept was created to meet the high requirements of aircraft construction which enables all production steps to be traced back and secures the reproducibility of the high quality of the components. This concept also contains documentation on the components in which all production steps from the extraction of raw material to the impregnation, and finally to the post-processing of the components are recorded.

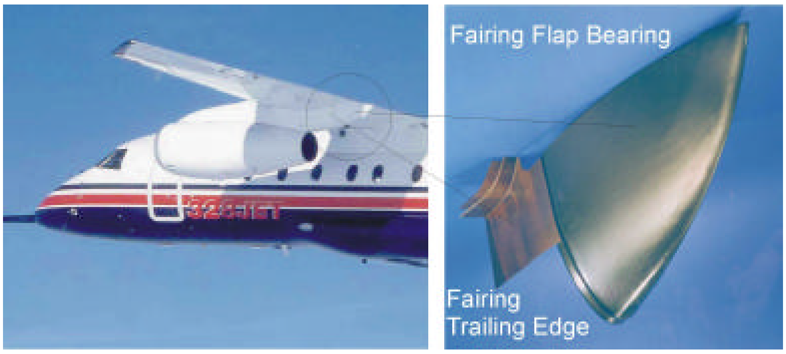


Fig. 4: CFRP Panelling elements on the engine pylon of the Do 328 Jet

The "Fairing Flap Bearing" and "Fairing Trailing Edge left/right" Components.

The “Fairing Flap Bearing“ elements form the rear covering of the engine pylon and are securely attached to the flaps. The components are stiffened on the inside with two stringers which are integrally manufactured. In addition, the components show a spherically curved surface. The weight of the component is less than1500g at a fibre content of 60%. The "Fairing Trailing Edge left/right" elements are fixed to the metallic engine pylon and, for this reason, have a lightning protection made of a copper mesh. A single component weighs less than 300g.

The Moulds [ref. 3]

The moulds have proven to be decisive for a reproducible production process. The investment costs for these moulds primarily depend on type, size, and complexity of the component to be manufactured. In addition, criteria such as dimension accuracy and service life are essential cost factors. Two different mould concepts were applied during the manufacture of the CFRP Fairing in order to research the advantages and disadvantages of each concept.

Integrally Milled Tool Made of Aluminium

Advantage: The advantage of the integrally milled aluminium tool is that it can be made out of one piece relatively quickly. The basis for production is a 3D CATIA model which is used to directly set up the milling program which eliminates the effort needed to make drawings from CAD files. An additional advantage is the long service life (more than 1000 casts possible) and the possibility to make repairs (welding and soldering).

Disadvantage: The thermal expansion coefficient of aluminium (α=23,8*10^{-6}) greatly deviates from the expansion coefficients of carbon fibre structures (α=ca. 1*10^{-6}) which can lead to the component remaining stuck in the mould during removal or can lead to deflections. An additional disadvantage is the high weight of the integrally milled tool which leads to handling problems and, due to the high specific thermal capacity, to extended heating and cooling phases.

Nickel Galvano Tools

Advantage: Nickel Galvano tools are distinguished by high surface quality and a long service life. The metal moulds which undergo an electrochemical nickel deposition process also have a low weight since there is less variation in the wall thickness compared with milled tools. As a result of the low mass, the heating and cooling periods can be kept short which, in turn, has a positive effect on the autoclave cycle periods. Nickel Galvano tools have also proven to be very useful in applications which call for utmost precision since it is possible to readjust the tool with special setting screws. Nickel Galvano tools can be soldered and welded which make them easy to repair.

Disadvantage : A great disadvantage of nickel Galvano tools is their price and lengthy manufacturing time. Since the Galvano process is very slow, a manufacturing time of 1 to 2 months must be taken into account in order to attain a wall thickness of 4 to 6 mm. The thermal expansion coefficient is α=13*10^{-6} (nickel), the order of magnitude of steel, which is acceptable but not optimal. The manufacture is similar to that of fibre composite tools in that a model structure is needed.

Production Preparation

In a first step, the required plies are cut out on a Gerber CNC wheel cutter. In addition to copper mesh as lightning protection as well as several isolation plies made of glass fibre fabric, cut-outs coated with tackyfier as well as uncoated cut-outs made of fine 5 harness carbon filament fabric are used. The tackyfier-coated cut-outs have the advantage that they become adhesive on one side at a certain temperature. In this manner, the stringer and other complex stiffening elements can be combined as so-called preforms. On the other hand, the uncoated cut-outs are used to lay down the component shape since they provide the necessary drapability. The great advantage of this combination of specialised semi-finished products especially lies in the reduction of the actual production time of the component since only few and for the most part preformed components have to be assembled. The employed tackyfiers from C. Cramer & Co are distinguished by an excellent compatibility with the employed Ciba epoxy resin system and thus enable a considerable improvement in the handling of the cut-outs without a reduction in quality.

After the component is laid down, the manufacturing equipment is covered with one or two vacuum bags which are sealed to the edges of the mould to make them vacuum tight. The hermetically sealed fibre set up is then evacuated in order to remove all disturbing gaseous elements from the production set up and also to check its impermeability. The second vacuum film is recommended with costly productions since this guarantees an almost 100% fail-safe process. A great advantage compared to the prepreg technology is the fact that the prepared production set up can be stored without risk since it does not contain time-critical components such as curing prepreg. This eases the situation with the autoclave and thus enables an optimal utilisation of the available autoclave capacity.

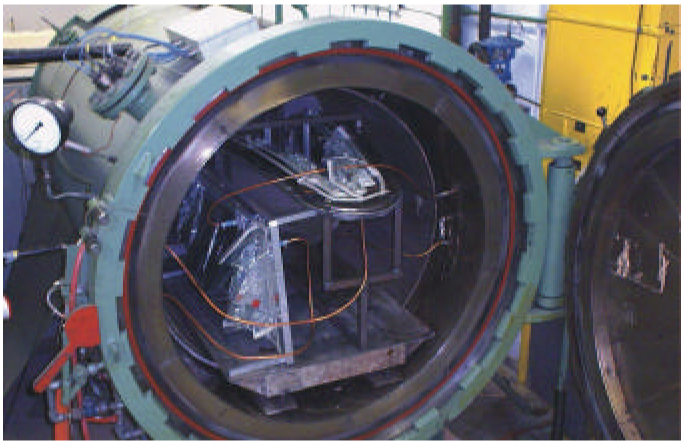


Fig. 5: Autoclave with two moulds

The Autoclave Process

In order to further reduce production costs, one “Fairing Flap Bearing” component and two “Fairing Trailing Edge left/right” components are manufactured together so that the available autoclave space is optimally used. In the actual injection process, the resin is injected simultaneously into both components at 70°C and at near autoclave pressure.

The measurement of the resin flow provides information on the impregnation process of the component and the point in time when the injection pressure must be reduced to set the desired fibre volume content. When the resin flow stops after adjustment of the differential pressure, the impregnation process is over and the fibre content has been set. The temperature of the component is then raised to the curing temperature of 120°C to cure the polymer. The component can be removed after about 90 min. when it has cooled off. A typical autoclave process involving injection and curing lasts less than 120 minutes.

The Finishing Process

The finishing process of the unfinished component is carried out by the Hahlbrock company in a 5-axis CNC machining centre. A saw blade set with diamonds has proven to be the best tool since it achieves the best productivity. The CNC machining centre is specially equipped for the processing of carbon fibre reinforced plastics since electrically conducted abrasive dust makes special protective measures necessary. The components are set in special vacuum clamping units which enable them to be quickly mounted and guarantee precise and secure positioning of the unfinished component.

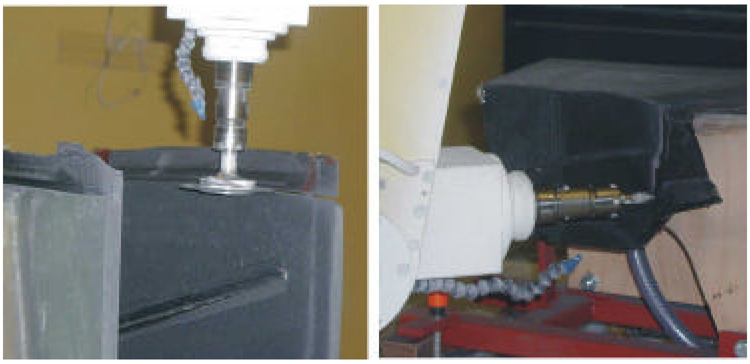


Fig. 6: CNC processing at the Hahlbrock GmbH company

COST ANALYSIS

The manufacturing process of the CFRP Fairings developed at the DLR should, on the one hand, prove the marketability of this technology and, on the other hand, contribute to an improved understanding of the requirements for creating a serial production at the DLR. An essential part of this project therefore is an exact determination of the costs incurred since this is extremely important for an overall evaluation of the project.

Project-Specific Cost Analysis

The last status of the serial production is shown for the project-specific analysis of the costs.

	Cost Factors:	Share	Scope
1.	moulds	4%	mould writeoff (5J)
2.	fibre and resin material	26%	semi-finished products
3.	ply cut out	5%	personnel, cutter writeoff (5J)
4.	lay-up and sealing of production set-up	29%	personnel, consumable material
5.	implementation of autoclave process	6%	personnel, DLR autoclave fee
6.	removal from mould/cleaning/final machining	15%	personnel, CNC machining
7.	quality assurance	8%	personnel
8.	project management, shipping etc.	7%	personnel

Table. 1: Relative share of different production areas of the SLI production costs

The allocation of the costs to the individual cost factors clearly shows that the manufacture of fibre composite components with the SLI method is decisively dominated by personnel resources. Especially the processing steps of the fibre material lay-up and sealing of the mould set up generate almost 30% of the production costs.

The share of costs of the fibre and matrix semi-finished materials is also higher than average since a high-quality carbon filament fabric is used during manufacture. The cost of the employed 120°C epoxy resin carries little weight compared to that of the fibre materials.

The share of costs for reprocessing the moulds and the CNC final processing are within the expected limits and do not have a greater optimization potential for the production batch.

The high share of project management and shipping costs are due to the great amount of flexibility required for this project since the delivery planning as well as the detailed design of the components was modified several times. The quality assurance costs are somewhat higher because the expenses incurred were considerably higher than the approved budget. However, these additional expenses are justified since the results of this new production are to be used in other projects.

The Autoclave Process and the automatic ply cut-out run up only approx. 11% of the costs during production which is much more cost-effective than originally expected. In addition, the last writeoff of the moulds mentioned above clearly shows that the very low cost share of only 4% provides good opportunities to support the production process with a greater optimization of the moulds in order to reduce costs in pre- and postprocessing phases which require a great number of personnel.

Comparison to Competing Production Processes

In order to compare the costs of competing production processes, the cost factors have been identified to help differentiate between the different processes.

	Cost comparison	SLI method	Prepreg method	RTM method	SCRIMP method
1	investment writeoff (5J)	10,6%	11,5%	20,0%	8,7%
2	cost of semi-finished products, consumable material	26,1%	37,3%	23,4%	25,7%
3	cut out/lay-up/sealing	32,1%	60,6%	29,4%	32,8%
4	production process (personnel)	4,1%	1,5%	3,1%	4,5%
5	removal from mould/cleaning	6,9%	6,9%	13,3%	6,9%
6	final processing	5,7%	5,7%	1,9%	5,7%
7	transportation, quality assurance, project management	14,6%	14,6%	14,6%	14,6%
	relative cost comparison	100%	138%	106%	99%

Table. 2: Comparison of different production technologies

The result clearly shows the cost advantages of the liquid resin method compared to the prepreg method because of the advantages in material costs and preparation efforts.

When looking at the RTM method it is interesting, that even a number of 500 produced pieces (5 years) can be manufactured economically as long as there are no expensive tool modifications and the lower composite component quality can be accepted.

The result of the evaluation of the SCRIMP method was not as good as expected. The advantage of the method is clearly with large components whose size is larger than the autoclave measurements or which cannot make optimal use of the autoclave volume, resulting in a greater autoclave cost share.

One aspect which has not been considered in this comparison is the component quality. With the VARI/SCRIMP and RTM methods, the quality is considerably lower than that of the autoclave-supported prepreg and SLI methods if the standard of quality is the reproducible manufacture of failure-free laminates with an even and high fibre volume content.

EXPERIENCE WITH SERIAL PRODUCTION

At a constantly rising production rate, 98 serial aircraft and 3 prototypes were each fitted with 2 "Fairing Flap Bearing" and 4 "Fairing Trailing Edge" components within the framework of the three-year project. Since the SLI method was employed for the first time in this project, a particular challenge was the quick solution of problems and the optimization of the production processes.

From the point of view of production, it has become quite evident that the productivity of the production concept and the quality of the components very much depend on the lay-up of the semi-finished fibre products and the quality of the fibre preform. Here, the sophisticated moulds combined with simple handling aids are the technological prerequisites for a failure-free and efficient production.

A potential source of error in the production area is the manual activity of lay-up of the cut-outs and possibly during the manual machining of the unfinished component. Even if these errors are easy to detect during the final quality control, the faulty components have to be reworked in most cases. On the other hand there is a great optimization potential particularly with manual work, especially with the components lay-up, by getting the appropriate employees specialized in specific activities and with improvement suggestions based on experience in the production process. In order to make use of this potential, a comprehensive training of the employees and involvement in the technological development are basic requirements.

A problem particular to composites with thin-walled, complex components is shown when the tolerances are kept at a minimum. In the production process tension is created by the different thermal expansion coefficients of the fibres and matrix which causes deformations. This process is reproducible and can be corrected by reworking the mould but the costs for such a modification of the mould are definitely not negligible.

Certain components had to be rejected during the run of the project for different reasons. “Fairing Trailing Edge” components had to be rejected because of lay-up errors (3/388) and machining errors (2/388). The considerably more complex “Fairing Flap Bearing” component had to be rejected because of vacuum leakage (5/206), lay-up errors (1/206), and faulty machining (6/206). However, consistent error analysis and corrections made it possible to maintain an error-free second half of the production process.

CONCLUSIONS

Based on the manufacture of complex CFRP Fairings for the Fairchild Do 328 Jet, it was possible to show that the Single Line Injection (SLI) production method developed at the German Aerospace Center (DLR) is an excellent method for the economical series production of complex components at the highest quality. It was possible to show that the autoclave provides decisive cost advantages especially with small series when a reproducible and high-quality component is required.

The short, two-year development period from laboratory processes to the successful series production, which is authorized for aerospace, was mainly possible with the exemplary cooperation with the Präzisionstechnik Gedern GmbH and Fairchild Dornier project associates. With their precise directions and quick decision-making, they proved their competence in the areas of effective project work and composite technology.

PROSPECTS

The new goals of the Institute of Structural Mechanics concentrate on the development of efficient and cost-effective preforming techniques since analysis of the production costs has shown that there is a great potential to further reduce production costs. To automate the resin injection process an automatic injection facility has been developed and tested for the manufacturing of large parts such as spars and ribs of up to 45 kg component weight.

The Do 328 Jet components will continue to be produced at INVENT GmbH in Brunswick which was founded in 1998 by the DLR and has been a supportive associate of the DLR since the beginning of the project. Further more INVENT was able to gain approval for the series production of the Nose Landing Gear Doors and other parts for the newly-developed Fairchild Dornier Do 728 in SLI Technology.

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