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DESIGN METHOD FOR PRESSURISED AND NON-PRESSURISED TAIL CARGO DOOR'S FAIRINGS COMPARTMENT IN TRANSPORT CATEGORY AIRCRAFT

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Abstract

The method for determining the main parameters of the tail cargo doors of transport category aircrafts is developed. A methodology for the ascertainment of these parameters has been described. An example based on an existing transport aircraft is considered. Gathered were information pertaining to the necessary design, operational and regulatory parameters and requirements of the international regulatory organisations Federal Aviation Regulations (FAR), Certification Specification (CS) and Aviation Regulations (AR). The principle of determining the dimensions of the cargo compartment, cargo floor and the hitting platforms, in the form of a ramp with a pressure door and ladders, is presented based on the initial data. Considering the described loading and unloading, as well as landing, operations, the dependence of the ramp length on the length of the cargo floor is ascertained. A method for designing a cargo door fairings in the transport category aircraft fuselage tail part is presented. The main features of the fairings compartment have been determined, together with those of its main components and their varieties, depending on the scheme of the cargo door. Information is provided on the fairings compartment structural elements parameters selection.

Keywords: fairings compartment; pressurised fairing; middle fairing; side flap; drove; fairing rotation axis; closed position locks

Type of the work: research article

1. CARGO COMPARTMENTS

At the initial stage of choosing a scheme and designing a cargo door, there must be availability of the following data: theoretical contours of the fuselage, overall dimensions of the cargo compartment, landing gear scheme, technical requirements for the cargo door, aircraft empennage scheme, nomenclature and configuration of equipment and loaded cargo, airborne means schemes and their dropping trajectories, schemes of exhaust parachute systems for dropped equipment and cargo, schemes of loading and unloading equipment, schemes of paratroopers seats, fences, and means of forced exhaust parachute systems, among others [1,2].

Thus, to construct a transport aircraft theoretical fuselage drawing, the required dimensions of the cargo compartment are needed. They are determined based on the technical requirements for the developed aircraft, depending on its class and purpose. The parameters affecting the cargo compartment and, as

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a consequence, the geometry of the fuselage are related to the flight, technical, takeoff and landing characteristics of the aircraft, as well as to the schemes of the landing gear, wing, empennage and cargo door.

Therefore, at the stage of preliminary design, determination of the cargo compartment parameters and that of the geometric shape of the fuselage are carried out together with the development of the aircraft layout, as well as the development of its wing, empennage, landing gear and landing gear fairing [3]. Then, there would be a consistency between their structural and power schemes and theoretical contours [12,13]. The result of this development is a fuselage preliminary theoretical drawing.

1.1. Cargo cabin main parameters determination

Based on the foregoing, in order to determine the parameters of the cargo compartment and the cargo door cutout, it is necessary to have at least the following data:

1. List of transported loads:
   - type (on pallets, in aviation or sea containers, wheeled or tracked vehicles, bulk cargo);
   - dimensions (L × B × H);
   - mass (with indication of the centre of gravity [c.g.]);
   - the cargo presence on the ramp, and its weight, dimensions and c.g.
2. List of airdrop cargo. Dimensions and combined contours of loads.
3. Mechanisation of loading and unloading operations: roller table equipment, invoice or built-in conveyor, and upper loading equipment (girder crane with telphers, on-board loading equipment [BLE]).
4. Requirements for the landing gear: 'squatting' on the main landing gear (MLG), an increase in the length of the nose landing gear (NLG) shock absorber.
5. Requirements for compliance with regulatory documents, such as CS [10,11], FAR [16], AP [4], etc.
6. Trajectories and dimensions, combined contour of dropped loads;
7. Minimum 'stick out' of the BLE rails relative to the cargo compartment sill (or the ramp rear end beam) to ensure the loading and unloading of platforms and pallets by a loader.

As an example, let us consider the nomenclature, layout and options for loading transported cargoes of the An-178 aircraft (Figs 1 and 2; Table 1).

Table 1. Transported loads nomenclature.

Transported loads	**Quantity**	**Weight, tones.**
Soldiers, people	90	10.8
Paratroopers, people	70	8.3
Injured on stretchers + on chairs, people	48 + 15	6.0
Containers, inch (m):		
Ml 96″ × 96″ × 125″ (2,438 × 2,438 × 3,175)	4	18.0
M2 96″ × 96″ × 238.5″ (2,438 × 2,438 × 6,058)	2	18.0
M3 88″ × 96″ × 125″ (2,235 × 2,438 × 3,175)	4	18.0
ID 96″ × 96″ × 117.8″ (2,438 × 2,438 × 2,991)	2	18.0
1C 96″ × 96″ × 238.5″ (2,438 × 2,438 × 6,058)	2	18.0
Pallets, inch (m):		
88″ × 108″ (2,235 × 2,743)	5	18.0
88″ × 108″ (2,235 × 3,175)	4	18.0
88″ × 108″ (2,438 × 3,175)	4	18.0
88″ × 108″ (2,438 × 6,058)	2	18.0

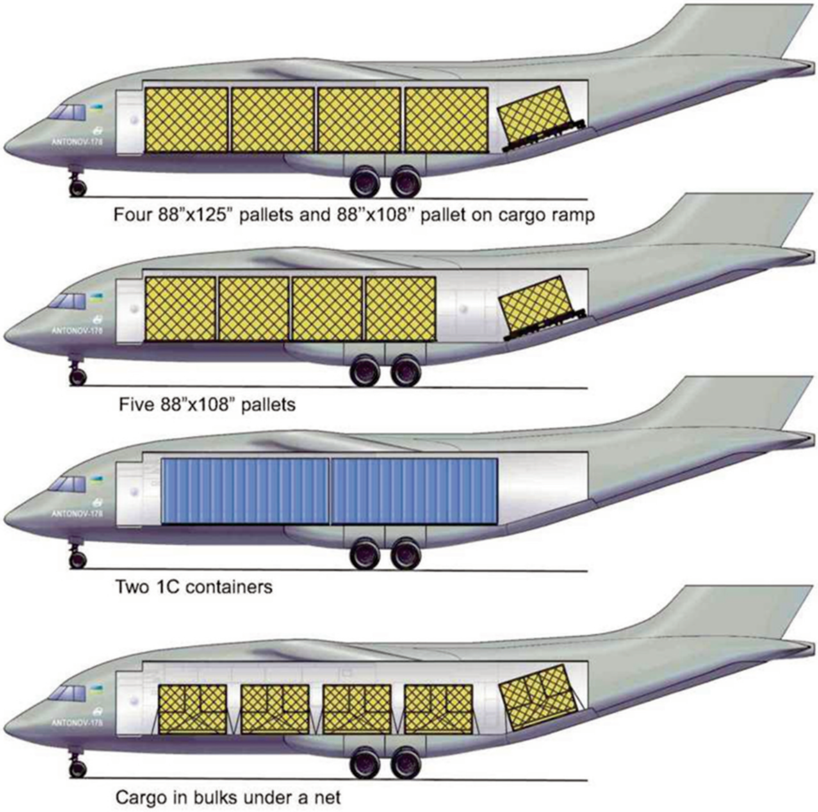

Figure 1. Options for the loads arrangement in the cargo compartment for transportation in containers and on standard aircraft pallets.

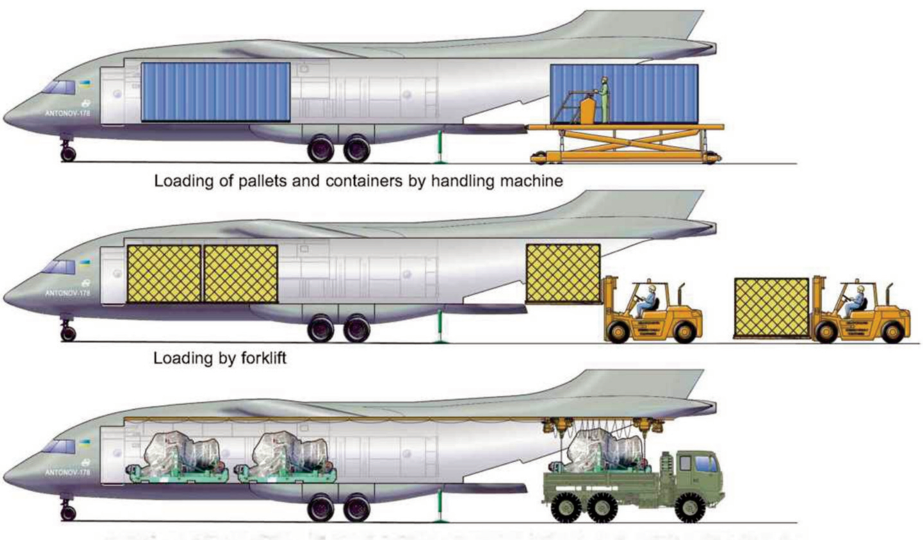

Figure 2. Schemes for loading cargo in containers and on standard aircraft pallets.

Let us consider the sections in the zone of fuselage single curvature of a typical construction and in the place where the wing centre section is installed (Fig. 3a,b). In this case, these will be the initial cross-sections for determining the dimensions of the cargo compartment of the designed aircraft. Their dimensions will depend on the overall dimensions of the transported loads.

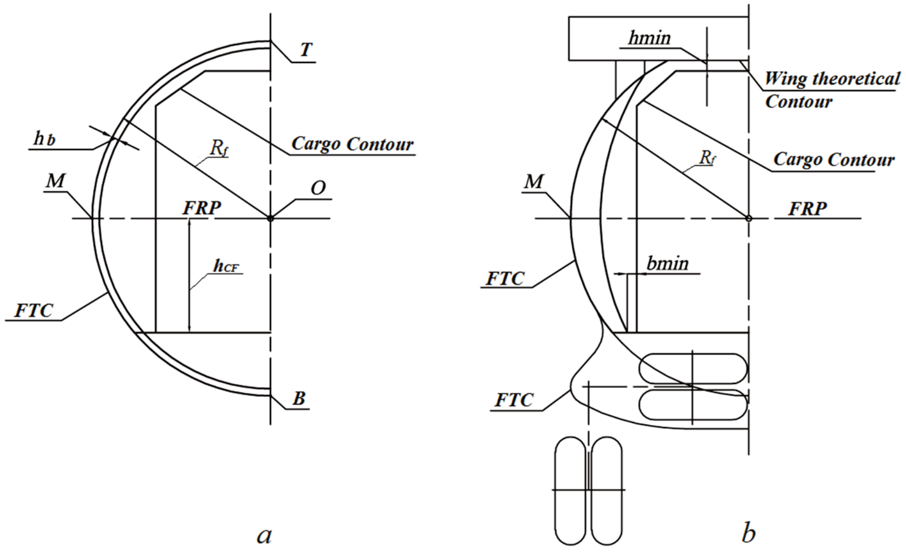

Figure 3. Sections of the cargo compartment in the zone of the fuselage single curvature (a – regular fuselage cross-section; b – fuselage cross section in the wing area).

So, when determining the length of the cargo compartment, it is necessary to consider the maximum length of the transported cargo or the sum of the lengths, if there are several of them. At the same time, the placement of cargo should ensure the possibility of penetration through the entrance doors into the cockpit and emergency escape by the crew through the provided doors and hatches in the air and on the ground, as well as by the accompanying personnel, if it is on the board. Therefore, as a rule, the placement of loads in the cargo compartment along the length should not be in the front part and overlap the existing exits (see Figs 1 and 2). So, the length of the cargo compartment will depend on the maximum length of the cargo or their sums plus the area of entrance doors and emergency exits and hatches, as well as the minimum front and rear clearances required for mooring the cargo.

$$L_{cc} = L_{\text{load}} + b_{ex} + 2b_{mo}$$

To determine the width and height of the cargo compartment, a similar algorithm needs to be used. To do this, it is necessary to possess information concerning the maximum width and height of the load $B_{lo\,\max}$ and $H_{lo\,\max}$. Thus, the width of the cargo compartment B_{cc} will be equal to the maximum width of the load $B_{lo\,\max}$ plus the minimum allowable clearances bmin to the fuselage structure (see Fig. 3b).

$$B_{cc} = B_{lo\,\max} + 2_{b\,\min}$$

It should be borne in mind that in $H_{\max}$ it is necessary to add the height of the equipment (roller conveyor) laid on the floor if the loading and transportation of loads (on standard aircraft pallets and containers) are provided for using them. Therefore, the height of the cargo compartment will be equal to the maximum height of the cargo plus the minimum allowable height clearance $h_{\min}$ to the centre section. If the aircraft provides for the installation of upper loading equipment, then the gap must be maintained considering the rails under the centre section, installed along the entire cargo compartment.

$$H_{cc} = H_{lo\max} + h_{\min}$$

The diameter of the fuselage is determined not only by the dimensions of the cargo compartment in the normal section of F-2 but also by the building height of normal frames h_{fr} and power frames for attaching the centre section (see Fig. 3b). However, the functionality of the aircraft cargo compartment in terms of placing cargo in it depends not only on its dimensions but also on the layout and design of the cargo door, which is influenced by many factors, beginning with the shape of the rear fuselage and ending with the layout and arrangement of the landing gear. It would be ideal to have a cargo door cutout equal to the dimensions of the cargo compartment, but in reality this is both a difficult task and non-critical, since it is necessary to consider not only the overall dimensions of the loads but also the conditions of their loading and unloading, as well as airdropping [7].

To determine the main parameters of the cargo door, it is also necessary to develop a theoretical drawing of the fuselage, which is produced in the form of theoretical outlines of the fuselage in a side view and planned in such a manner as to provide a preliminary breakdown of the distances between the frames. It is wholly feasible to show diagrams of sections aligned along the axis of symmetry of the aircraft, made according to this breakdown. The know-how material pertaining to the creation of the theory of the tail section have been explained in the literature [5,6].

In the theoretical drawing of the fuselage sets, several parameters are used, some examples of which are the following: the length of the cargo floor, the location of the cargo compartment sill, the configuration of the vertical and horizontal tail and the axis of their longerons, the configuration of the horizontal tail root rib, the location of the MLG and the position of the ground for an empty equipped aircraft [14,15].

As a rule, a theoretical drawing of an aircraft landing gear fairing is issued separately and may be necessary during the development of a cargo door.

The theoretical drawing of the fuselage allows the building of any section required for the development of the cargo door. At the initial design stage, the theoretical drawing of the fuselage is used to determine the geometric parameters of the sill, ramp, cargo beam, cutout and doorway of the cargo door.

1.2. Determining the length of a sloped floor

To enter the cargo compartment of the aircraft and load and unload equipment through the cargo door, it must be equipped with a sloped floor. The sloped floor is formed when the ramp, ladders and other components of the cargo door are laid out on the ground. The length of the sloped floor depends on the angle of its inclination to the ground α and the height of the sill h_s. The angle α is specified in the technical requirements for the cargo door, whereas hs depends on the landing gear layout and the layout of the aircraft cargo compartment.

It is known that the centring range is set relative to the toe of wing average aerodynamic chord and is set as a percentage; the MLG is located at a distance *e* from it. To achieve a uniform loads distribution, a ratio of the cargo compartment lengths that results in the sum of L1 and L2 being equal to the consolidated load when L1 = L2 would be the most favourable. Figure 4 shows how the ratio of L1 and L2 affects the sill height h_s and the length of the sloped floor.

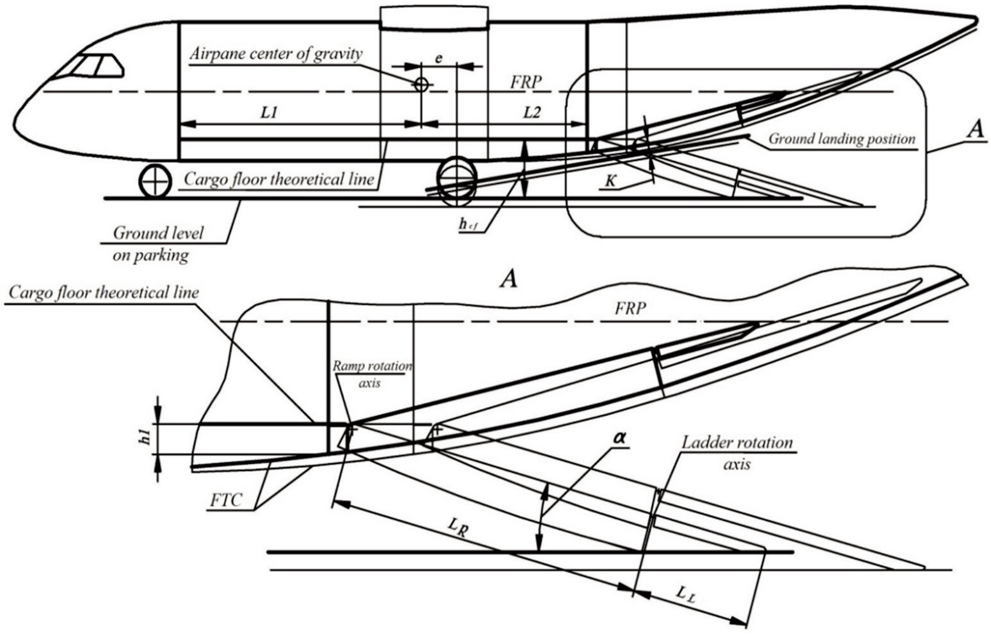

Figure 4. Scheme for determining the length of the sloped floor and the nodes of the ramp hinge.
FRP, fuselage reference plane.

The sill frame bottom height h_1 is determined constructively from the condition of the cargo door ramp hinge. The lower line of the fuselage bypass is connected with the ground line during landing and clearance K. The position of the main strut wheel during deformation and amortisation of the pneumatics, as well as the ground level during landing and in the parking lot, are set in the aircraft landing gear diagram. The value of hs corresponds to a certain ratio of the quantities L1 and L2. With an increase in L2, h_s increases, since h_1 remains unchanged and it is necessary to move down the lower line of F3; and therefore, to ensure clearance K, the landing gear is lengthened. With a decrease in L2, the height of the cargo compartment sill decreases, and therefore so does the length of the inclined floor at a given angle α.

The change in L2 has a significant impact on the layout of the cargo door and the parameters of its components. When dropping the maximum load from the ramp, the limiting value L2 + Lr is determined by the aerodynamics of the aircraft and is a constant value for this type of aircraft. Thus, as L2 decreases, Lr increases. An increase in Lr reduces the length of additional elements of the inclined floor and simplifies the cargo door scheme.

An increase in L2 lengthens the sloped floor and shortens the ramp, which leads to a complication of the cargo door, since the long ladders are difficult to fit in F3 and additionally it is difficult to ensure their operability under the condition of increased floor length; on the other hand, using a short ramp comes with its own associated disadvantage, since a short ramp must be equipped with mechanisated supports. During arranging the transport aircraft cargo compartment, in order to improve the initial data on the cargo door design, it is necessary to select the optimal ratio of the L1 and L2 values. In this case, the surface of the ramp can be used for storing and transporting loads.

2. CARGO DOOR FAIRING COMPARTMENT TYPES

The cargo door fairing compartment refers to the movable parts of the cargo door containing a drive, locks and other devices, hinged or otherwise, attached to the fuselage, forming its shape in the place of the cargo door cutout. It takes the acting loads and performs functions according to the cargo door scheme.

The fairing compartment has a great importance in the formation of the cargo door cutout and, as a consequence, the transport capabilities of the aircraft as a whole. As a rule, the cutout of the cargo door has a smaller cross-section than the cargo compartment and therefore is decisive in the formation of the aircraft transport capabilities [8].

Depending on the scheme of the cargo door, the fairings and flaps can be solid, multi-link, opening inward or outward of the fuselage, and receiving or not receiving pressurisation loads in the aircraft cargo compartment.

The structural and load-bearing diagram of the cargo door flaps, interconnection, kinematics, and methods of fixing and controlling individual structural units are laid down in the cargo door diagram and in its theoretical drawing, as well as in the theoretical drawing of the fairing compartment when dividing the cargo door into separate compartments.

2.1. Cargo door pressurised fairing compartment

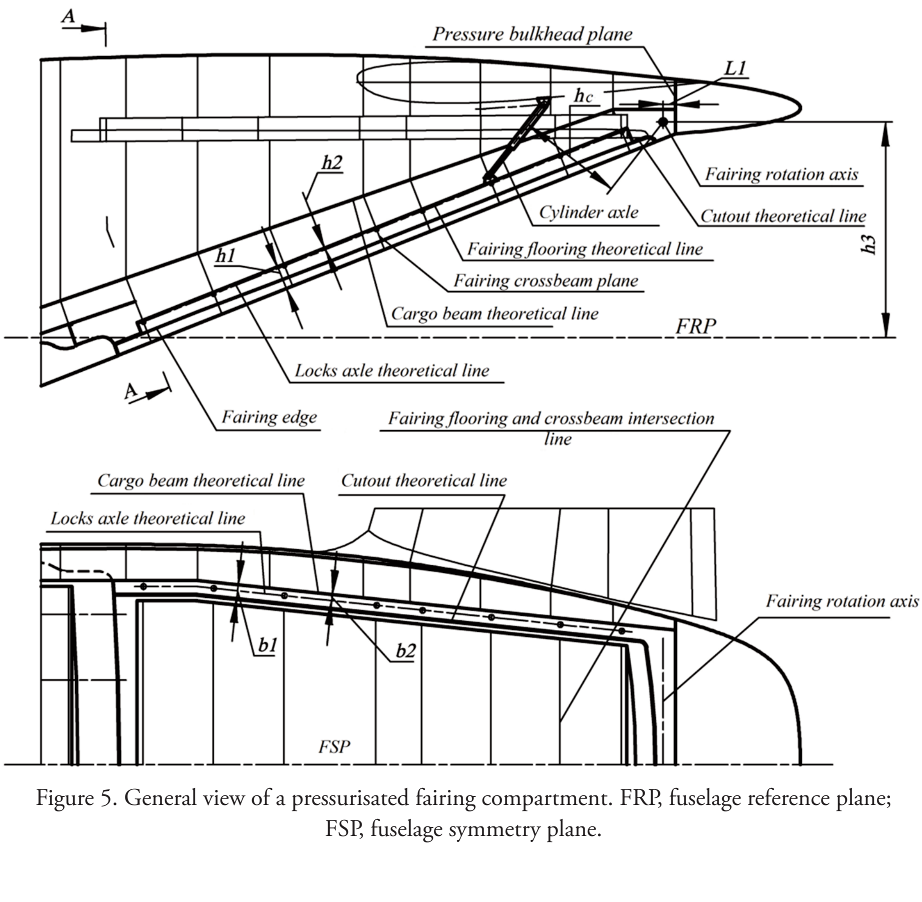

Figure 5. General view of a pressurisated fairing compartment. FRP, fuselage reference plane; FSP, fuselage symmetry plane.

The configuration of the ramp and the fairing, hinged in the aft fuselage, determine the cutout of the cargo hatch in type A schemes. The main characteristic of the fairing compartments, in this case, shown on the Figure 5, is that the fairing is located in a pressurised zone and as a ramp takes over the pressure load. Therefore, the fairing is made integral with the possibility of its retraction inside the fuselage when the cargo door is opened. This condition requires the designing of an appropriate geometric shape of the fuselage.

The structural and load-bearing scheme of the fairing assumes the presence of external and internal skin and a frame in the form of transverse beams set connected by structural longitudinal elements. For the perception and transmission of excess pressure, the beams are equipped with uncontrolled locks interacting with the axes of the brackets installed on the fuselage board [9].

Figure 1 shows the cargo door in side and plan views. Dimension h_1 sets the building height of the fairing. Dimensions h_2 and b_2 set the theoretical line of the locks axes relative to the theoretical line of the fairing deck and the theoretical line of the cargo door beam. Dimension b_1 defines the theoretical cut line from which the fairing is trimmed with a given clearance. The selected fairing rotation axis is specified by the dimensions L1 and h_3.

The power of the fairing cylinder is selected in accordance with its stroke, shoulder hc, fairing mass and external loads acting on it.

The fairing crossbeams axes are selected in accordance with the breakdown of the fuselage frames perpendicular to the fairing deck.

Figure 6 shows section A–A of Fig. 5.

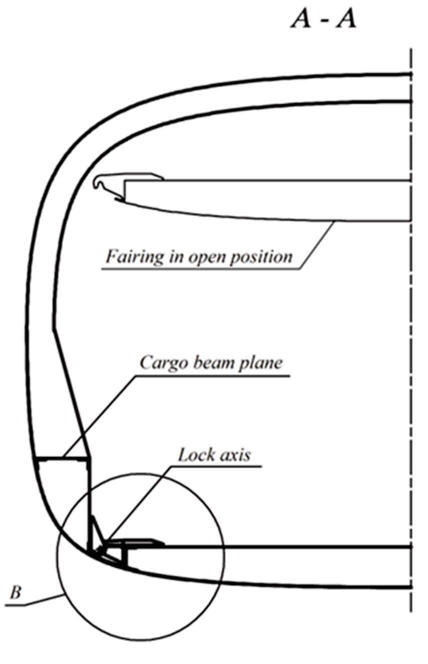

Figure 6. Sectional view of a pressurisated fairing compartment.

Hook 1, fixed on the cargo door fairing and interacting with axis 2 of bracket 3 installed on the fuselage side, transfers to the fuselage the load received by the fairing cross beam from the pressurisation inside the fuselage. The hooks and axes of the uncontrolled fairing locks are also designed to hold the sides of the fuselage in the transverse direction.

Under the influence of the control cylinder, the fairing is removed inside the fuselage, after which it is fixed with the locks of the open position. In the closed position, the fairing is also locked with locks, which prevents its spontaneous opening when the external pressure exceeds the pressure inside the aircraft cargo compartment.

Figure 7 shows extension B of Fig. 6. On side beam chord 6 of the sash, a sealing profile 5 was installed, interacting with fuselage side edging chord 7. Dimension b_4 sets the gap between sealing profile 5 and bracket 3 when the fairing is opened. Dimension b_3 sets the gap between hook 1 and bracket 3 when the fairing is opened.

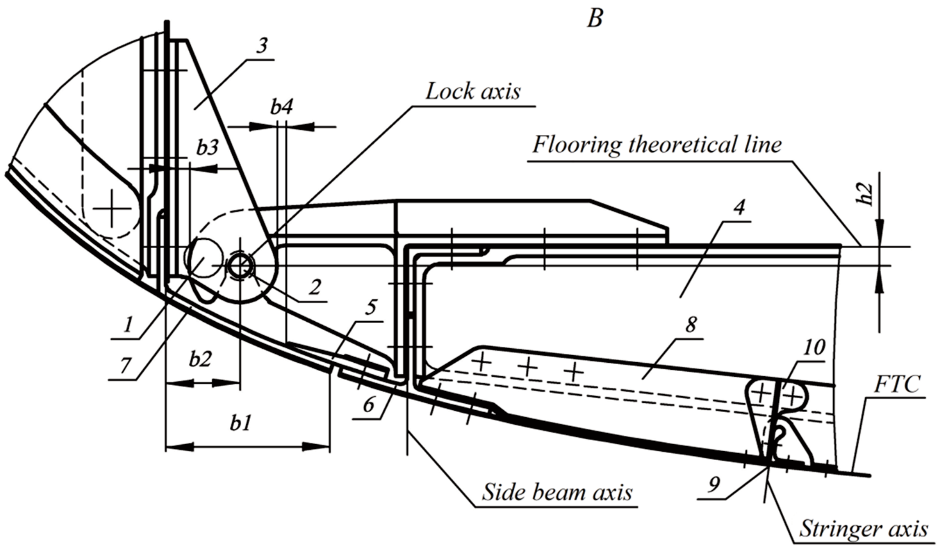

Figure 7. Fairing closed position lock. FTC, fuselage theoretical contour.

Dimensions h_2 and b_2 set the coordinates of the locks axes, whereas size b1 sets the theoretical cutout line for the cargo door. Crossbeam 4 is connected to the fairing casing with an expansion joint 8. A stringer 9 is attached to beam 4 with a knit 10.

2.2. Cargo door non-pressurised fairing compartment

The fairings and flaps of the cargo hatch types B and D are located in its unpressurised compartment. The fairings and flaps form the shape of the fuselage in the place of its cutout, perceive the loads acting on them and perform their functions in accordance with the structural scheme of their execution. The above scheme of the cargo door is made in the theory of the fuselage tail section, which has the smallest surface area. Therefore, the fairing of the cargo door for such surface can only be made with multiple links.

Figure 8 shows the cargo door fairing compartment, which consists of two side flaps that open outward of the fuselage and the central and tail fairing that retract into the fuselage.

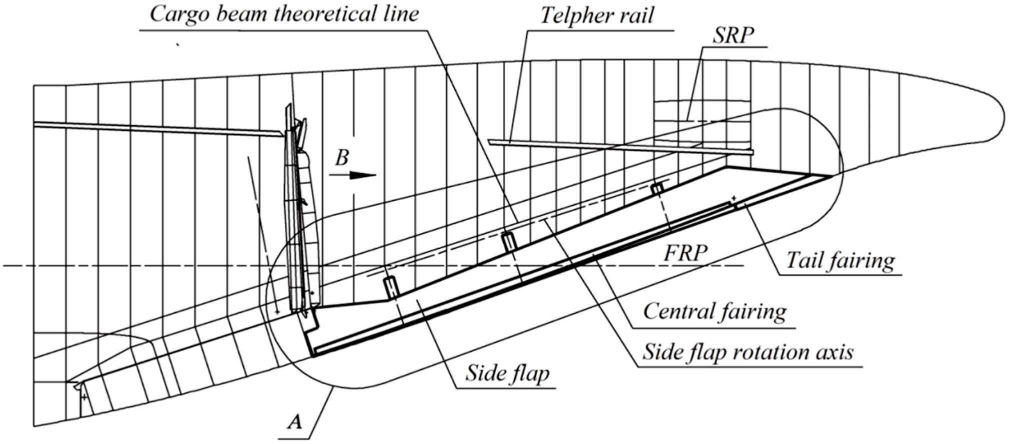

Figure 8. Main view of fuselage tail part with non-pressurisated fairing compartment. FRP, fuselage reference plane; SRP, stabiliser reference plane.

Figure 9 shows offset A of Fig. 8 and view C of offset C.

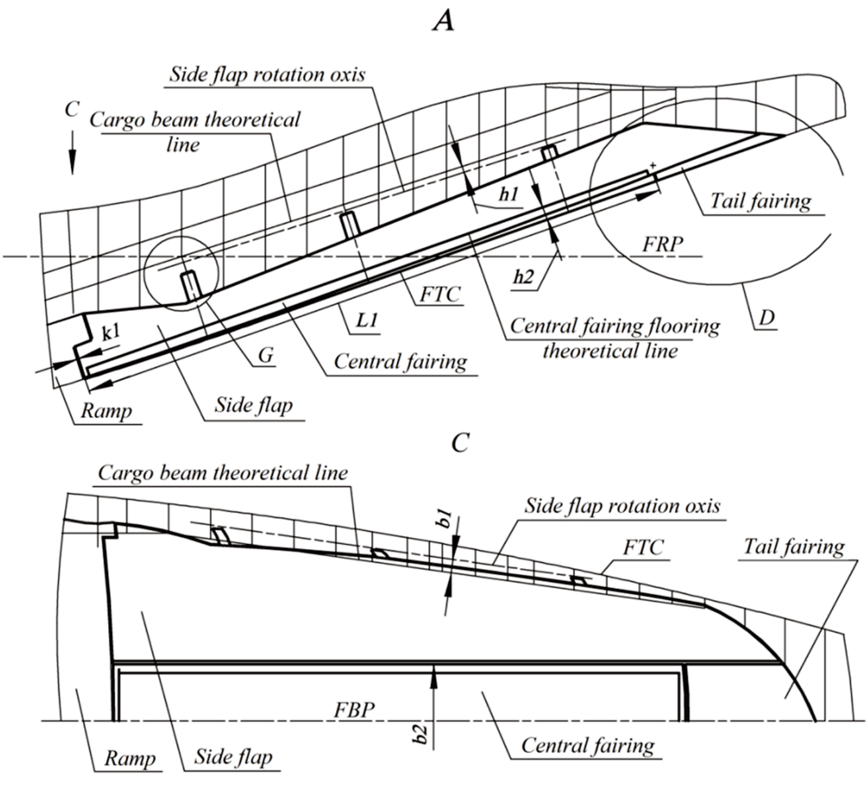

Figure 9. Main and bottom view of non-pressurisated fairing compartment. FRP, fuselage reference plane; FTC, fuselage theoretical contour; FSP, fuselage symmetry plane.

Figure 10 shows view B of Fig. 9.

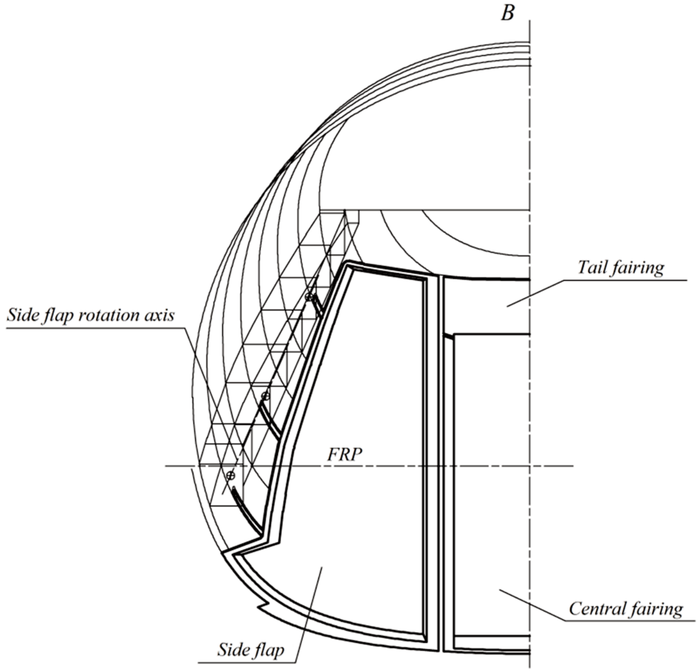

Figure 10. Sectional view of non-pressurisated fairing compartment. FRP, fuselage reference plane.

Figure 11 shows offsets G and D of offset A in Fig. 9.

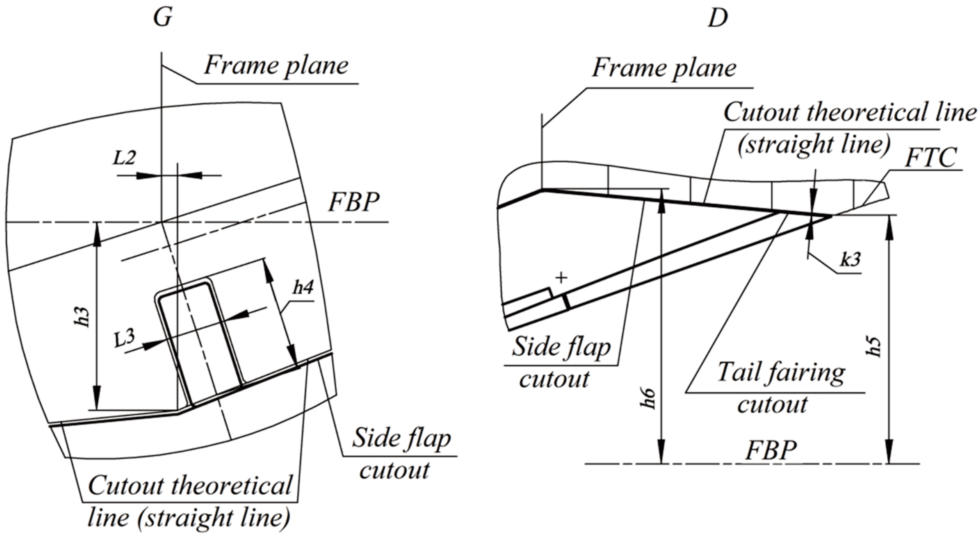

Figure 11. Profiling of the cutouts for the side flaps hinge nodes and determination of the cut of the fairing compartment tail section. FRP, fuselage reference plane; FTC, fuselage theoretical contour.

The outer surface of the flaps is a movable component of the aft fuselage, covering the cutout in the fuselage when the aircraft cargo door is closed. In the presented version of the cargo door, the cutout in the fuselage is defined by three straight lines, conjugated by the fillet radii. At aft side, a straight line is defined by the dimensions h_5 and h_6. In the middle of the cut, the straight line is defined by the dimensions h_3, L_2 and h_6. The front part of the fairing compartment cutout is formed by a straight line connecting the end point of the theoretical cutout line in the ladder compartment and the beginning of a straight line defined by the dimensions h_3 and L2.

The side flap axis is set by the dimensions h_1 and b_1. b_2 is the width of the central fairing. Dimension h_2 from the straight section of the fuselage theoretical contour (FTC) is the construction height of the middle fairing.

Sizes L3 and h_4 set the cutout in the fuselage skin for the side flap hinge units.

2.2.1. Side flaps

The side flaps are attached to the fuselage board by three hinge assemblies equipped with scutes for unhindered opening of the flaps (Fig. 12).

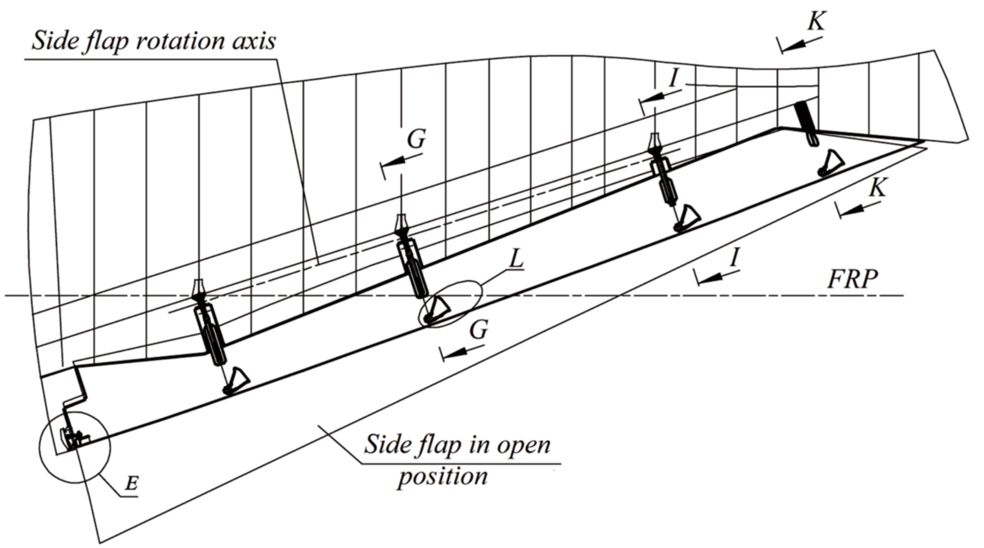

Figure 12. Side flaps catchers location. FRP, fuselage reference plane.

Side flaps, usually, are made of multilayer carbon fibre material. The space between the outer and inner skin is filled with honeycomb filler. In addition to the hinge units, the side flap is equipped with catchers interacting with the rollers of the middle fairing, as well as stops installed along the front end and at the end of the flap. Catchers are designed to fix the side flaps in the closed position. At the points of the hinge assemblies' attachment, clamps and stops, the space between the outer and inner panelling of the flap is filled with foam filler.

Figure 13 shows section G–G of Fig. 12. Section G–G is rotated clockwise.

The hinge unit of the side flap consists of brackets 1, 2, 3 and 4. Bracket 4 is fixed to the cargo door beam. Bracket 1 is fixed to the side flap. Mutually connected brackets 2 and 3 are hingedly attached to brackets 1 and 4. A shield of the side flap hinge assembly is attached to bracket 1. k_2 is the gap between the central fairing and side flap. h_3 represents the construction height of the side flap.

The side flap cylinder is pivotally connected to brackets 1 and 4.

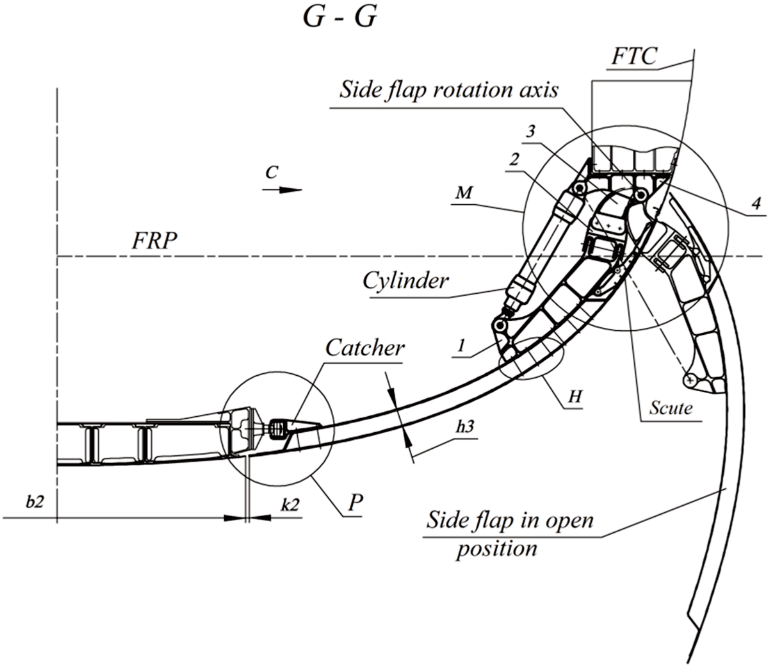

Figure 13. Sectional view of the side flaps. FRP, fuselage reference plane;
FTC, fuselage theoretical contour.

2.2.2. Central fairing

The geometric parameters of the central fairing are given in Fig. 10, where L1 is the fairing length, b2 is the fairing width and h2 is the fairing construction height.

The central fairing is made, as a rule, of carbon fibre material and consists of outer and inner skin, as well as side, longitudinal and end beams. Diaphragms are installed between the side and longitudinal beams, to which the outer and inner skins are attached.

In the middle part, the fairing is pivotally connected to carrier 10 by means of a bracket 20, which is pivotally attached to the top of the aircraft cargo compartment. In the rear part, the fairing is equipped with a hinge unit 30. Hinge unit 30, with its carriages, interacts with the rails installed in the aft fuselage.

A flap control cylinder is pivotally connected to carrier 10. During lifting of the central fairing, carriage 30 moves along rail 40, while the rollers of the fairing disengage with the catchers of the side flaps. In the final position, the central fairing is fixed with an open position lock.

Figure 14 shows the central fairing in a side view.

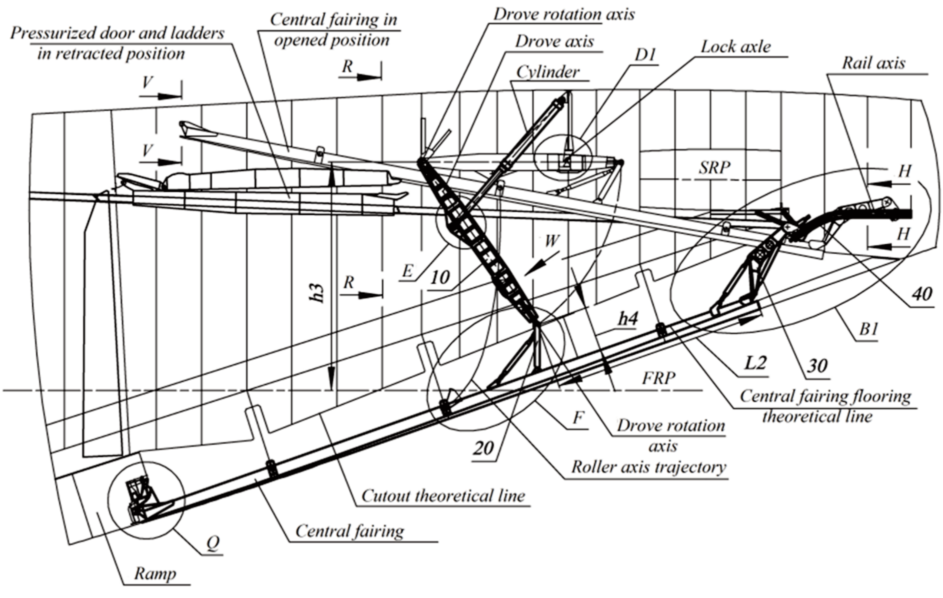

Figure 14. Central fairing controlling. (10 – carrier; 20 – carrier bracket; 30 – rear hitch assembly; 40 – rail.) FRP, fuselage reference plane; SRP, stabiliser reference plane.

Figure 15 shows the section V–V of Fig. 14.

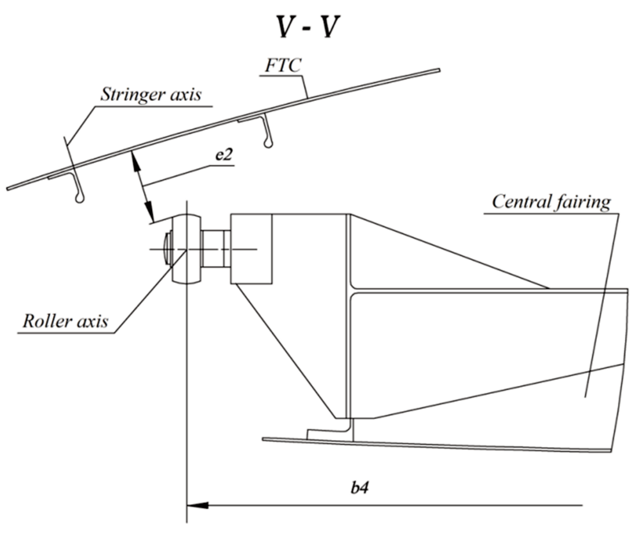

Figure 15. Central fairing in the open position. FTC, fuselage theoretical contour.

Dimension e_2 sets the gap between the roller of the central fairing front support and the fuselage structure. b_4 is the size from the roller axis to the fuselage symmetry plane (FSP).

2.3. The cargo door fairing compartment for a double-deck fuselage

The fairing and flaps of the cargo door of scheme D are made similar to those of scheme B, which design, hinge and locking system are described in detail above.

The scheme D cargo door fairing compartment consists of two side flaps and one central fairing.

The side flaps are fixed on the fuselage board with their hinge assemblies and open with cylinders to the outside of the fuselage.

The central fairing is held by a carrier, hinged at the top of the fuselage, and rear hinge units with carriages interact with side rails installed in the aft fuselage. The middle fairing is cleaned inside the fuselage with a cylinder pivotally attached to the carrier. In the open position, the central fairing is locked with an open position lock.

As in B scheme, the central fairing is equipped with rollers, and the side flaps are equipped with catchers. After the side flaps are closed, when the middle flap moves, its rollers engage with the side flap catchers and perform their mutual locking. In the closed position, the central fairing is fixed with a lock installed on the side rail.

Figure 15 shows the fairing compartment of scheme D cargo door.

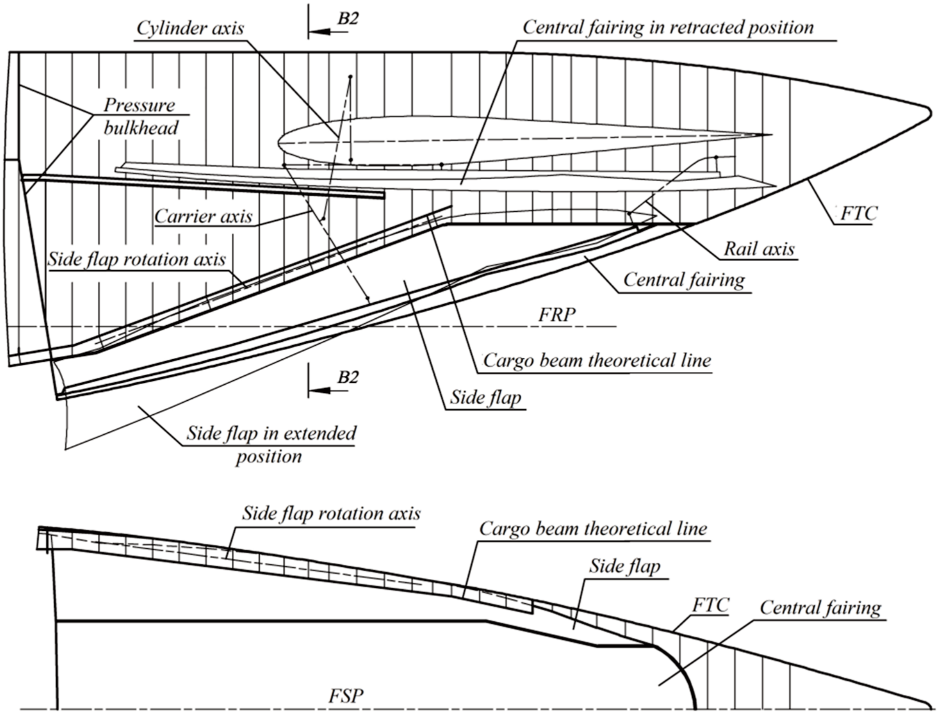

Figure 16. Fairing compartment of a double-deck fuselage. FRP, fuselage reference plane; FTC, fuselage theoretical contour.

Figure 17 shows section B2–B2 of Fig. 16.

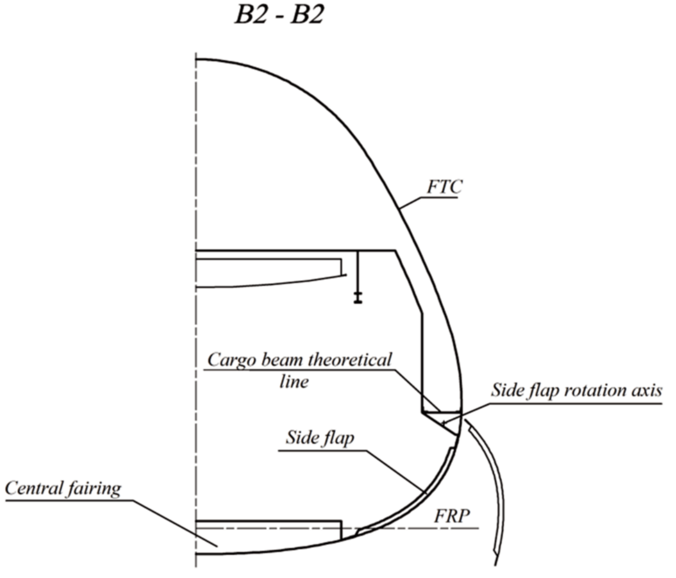

Figure 17. Sectional view of the double-deck fuselage fairing compartment.
FRP, fuselage reference plane; FTC, fuselage theoretical contour.

Figure 18 shows the type B tail cargo door master geometry with a non-pressurised fairing compartment.

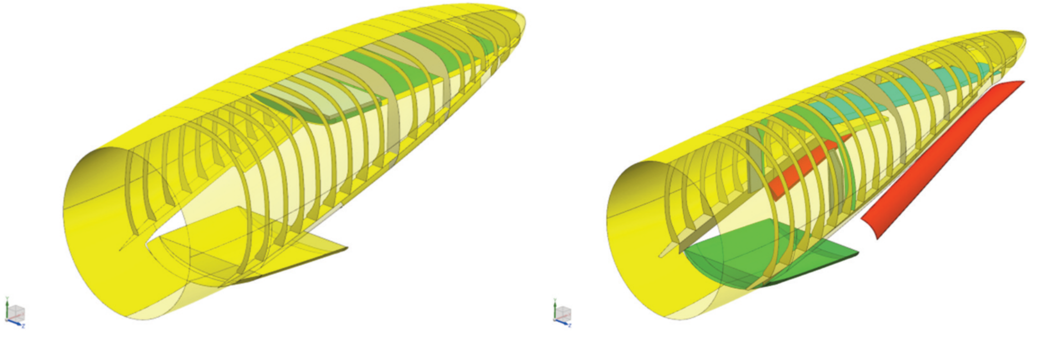

Figure 18. Cargo door pressurised and non-pressurised fairing compartment.

3. CONCLUSIONS

Work has been done to describe a design method for the cargo door fairing compartment in the aft fuselage. As a result of the work, the types of fairing compartments were classified into sealed and non-sealed categories. Typical for a pressurised fairings compartment is the presence, as a rule, of one pressurised fairing, which performs the functions of both a sealed partition and an element that describes the outer surface of the aft fuselage. In this case, a design feature of such fairings compartment is the need to implement power locks in a closed position to transfer the load from the excess pressure acting on the fairing to the fuselage frame. It is also typical to perform the sealing of the fairing cutout. The shape of the fuselage and its tail section is not typical for a non-pressurised fairings compartment. It can be either cylindrical or described by two circles (in the form indicated in Fig. 8). In this case, the number of moving elements can be completely different. In each case, the control of the movable elements can also be different. Therefore, this paper presents the most common examples. The commonest example is, as a rule, the combination of a three-leaf fairing compartment with a central fairing that retracts inside of the fuselage, and two side flaps that open outward. The main drive and locking devices of the fairing compartment, as well as their design principles, are described.

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