WEIGHT ESTIMATION OF COMPOSITE SECONDARY STRUCTURE

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Abstract

Composite material has been vastly used in today aerospace industries, perhaps more than any other engineering material. This paper will discuss and serves as a guideline for weight estimation of composite secondary structure in generic form by using the composition of basic geometries and calculates the weight based on its resemblance. It is intended to be use only as preliminary weight estimation for prepreg and hand layup. Although the used of state of the art software such as Finite Element Analysis (FEA) and FibreSim can accurately calculates the weight of composite secondary structure, but the cost associated with it, is beyond the affordability of most small to medium scale design and analysis organizations.

Nomenclature

N	Number of L or T section stiffener
n	Number of plies
W_C	Unit aerial weight of carbon ply
W_{FA}	Unit aerial weight of film adhesive
W_G	Unit aerial weight of glass ply
W_P	Unit aerial weight of paint
ρ_C	Density of honeycomb core
ρ_{EC}	Density of sealant for edge closure
ρ_{ES}	Density of sealant for tapering edge strengthening
ρ_{FCP}	Density of sealant for fastener core potting
ρ_{FO}	Density of sealant for fastener overcoat
ρ_{FS}	Density of sealant for fay surface sealing

1 Introduction

The extensive used of composite material in aerospace structural design is mainly stimulated from the weight saving aspect of view to achieve long endurance flight and higher gross payload. In addition to this, the main advantage of using composite material is its ability to reduce the number of parts and weight in an assembly.

Often composite structure is best describes by weights and design group as an assembly of components. This can be shown by the amount of constituent in one composite structure. Judging from the complexity of the constituent, weights analysis of composite structure is somehow prove to be time consuming and tedious for most engineer.

A more robust and simple method based on assembly of geometries is been derived for the estimation of weight on composite secondary structure. This method is to divide the secondary structure into multiple basic geometries and calculate the weights based on its resemblance. The overall secondary structure weights are the composition of the sub-divided basic geometries. This method has been proved to be reliable and close to exact with the weighed weight.

2 Materials

For the weights engineer, knowledge of the constituent material properties and understanding of the origin of those properties is important for the task of estimating the composite structural weight.

Generally, the main materials constitutions for composite secondary structure are fibres (carbon or glass), honeycomb core, synthetic core, film adhesive, metal mesh and paint (primer and top coat).

3 Weight Calculation

Weight calculation for composite secondary structure can be divided into few categories. These are:

- Sealing
  - Fay surface
  - Fastener core potting
  - Fastener overcoat
  - Honeycomb core edge closure
  - Honeycomb core tapering edge strengthening
- Sandwich flat panel (full honeycomb core)
- Sandwich flat panel (honeycomb core with tapering on edge)
- Sandwich flat panel (multiple foam core)
- Monolithic panel
- Solid laminate integrally stiffened flat panel
- Sandwich curve panel

3.1 Sealing

Weight estimates for sealant are generally inaccurate due to so many variables. Estimating areas to apply sealant are easily underestimated and application of adhesive is likely to be more than required.

While there are various methods for sealing of composite secondary structures, the most common methods are fay surface, fillet, fastener core potting, fastener overcoat honeycomb core edge closure and honeycomb core tapering edge strengthening.

3.1.1 Fay Surface Sealing

Fay surface sealing is a process that seals two surfaces come into contact or mating during a joint. It also aid in corrosion protection between dissimilar materials. Refer figure 1 for geometry of fay surface sealing.

Area of fay surface sealing, A_{FS}:

$$A_{FS} = gL \qquad (1)$$

Sealant weight for fay surface sealing can be estimated from:

$$W_{FS} = t_{FS} A_{FS} \rho_{FS} \qquad (2)$$

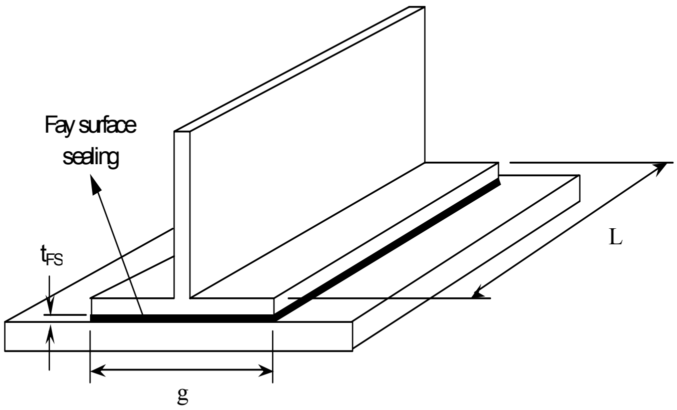

Fig. 1. Fay Surface Sealing between T Channel and Solid Laminate Plate

3.1.2 Fastener Core Potting

Fastener core potting involves drilling a hole into one side of the honeycomb, placing a fastener insert into the hole and then forcing adhesive through the top and down around the insert, to set it in place.

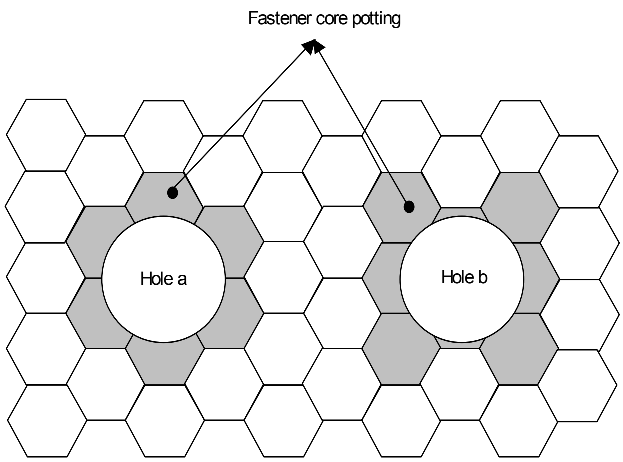

Fig. 2. Area of Fastener Core Potting

Presumed the honeycomb core cell size is 3.2mm (1/8") and is resemblance of hexagonal shape with $\alpha = 30^0$.

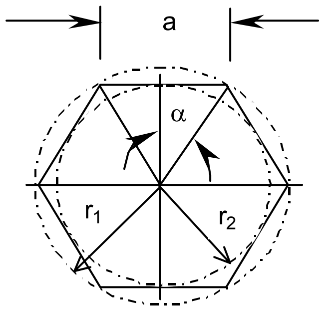

Fig. 3. Honeycomb Core Cell Size

Length of one side of hexagon, a:

$$a = r_2 2 \tan\alpha \tag{3}$$

where r_2 is the radius of the circle inside the hexagon. In this case it is $= 3.2/2$ mm

Radius of outer circle, r_1:

$$r_1 = \frac{a}{2\sin\alpha} \tag{4}$$

Area of the hexagon, A_H:

$$A_H = \frac{6a^2}{4\tan\alpha} \tag{5}$$

Presumed a bolt of 4.763mm (3/16") diameter with the insert of 13.589mm (by using Shur-Lok's bonded spacer for non-metallic panels SL5128 series) diameter is inserted into the core.

For hole a:

Area of fastener core potting, A_{FCP}:

$$A_{FCP} = 6A_H - \pi r^2 \tag{6}$$

Sealant weight for fastener core potting can be estimated from:

$$W_{FCP} = A_{FCP} t_C \rho_{FCP} \tag{7}$$

For hole b:

Area of fastener core potting, A_{FCP}:

$$A_{FCP} = 8A_H - \pi r^2 \tag{8}$$

Sealant weight for fastener core potting can be estimated from:

$$W_{FCP} = A_{FCP} t_C \rho_{FCP} \tag{9}$$

3.1.3 Fastener Overcoat

Fastener overcoat is where sealant been applied over exposed fastener sections in order to prevent arching and maintain a fuel seal. An approximation for fastener sealant is to consider it to be hemisphere.

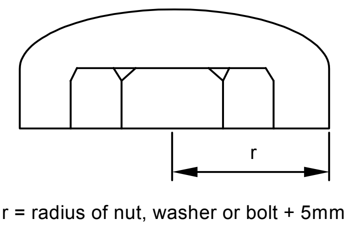

Fig. 4. Coverage of Sealant for Fastener Overcoat

Volume of fastener overcoat (hemisphere), V_{FO}:

$$V_{FO} = \frac{2}{3}\pi r^3 \tag{10}$$

Sealant weight for fastener overcoat can be estimated from:

$$W_{FO} = V_{FO} \rho_{FO} \tag{11}$$

3.1.4 Honeycomb Core Edge Closure

Edge closure is often happening to flat sandwich panel where the skin is abruptly terminated at the edge of the honeycomb core. Due to the sensitivity of honeycomb core towards moisture and water ingress, the edge is usually fill with adhesive sealant.

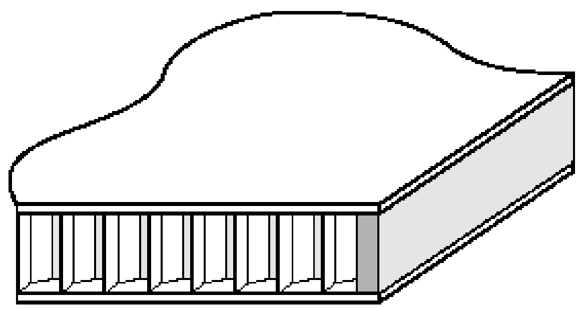

Fig. 5. Isometric View of Sandwich Flat Panel with Sealant as Edge Closure

Typical weight estimation for the adhesive sealant on edge closure is by considering the full geometrical honeycomb core cell (for conservative it is assumed that half the cell is being cut off and filled with sealant, while additional sealant is presumed half the size of the cell for reinforcing purpose). Refer figure 6 for detail.

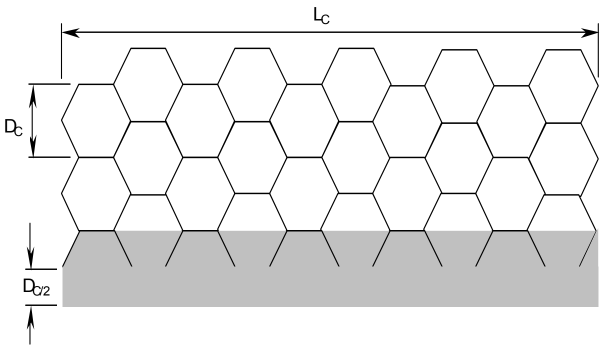

Fig. 6. Area of Sealant on Edge Closure for Flat Sandwich Panel

Area of half the hexagon core cell (trapezoid), A_{HH}:

$$A_{HH} = \frac{A_H}{2} \tag{12}$$

where A_H can be found from section 3.1.2 in this paper

Area of additional sealant, A_{AS}:

$$A_{AS} = \left(\frac{D_C}{2}\right) L_C \tag{13}$$

where D_C is the diameter of the cell

Sealant weight for edge closure can be estimated from:

$$W_{EC} = (A_{HH} + A_{AS}) t_C \rho_{EC} \tag{14}$$

3.1.5 Honeycomb Core Tapering Edge Strengthening

Thick honeycomb core with tapering on edge will tend to crush during curing if the tapering angle is more than 25^0. A solution to this is to strengthen the edge with sealant. It is estimated that 3 cells depth around the perimeter of honeycomb is completely filled with sealant.

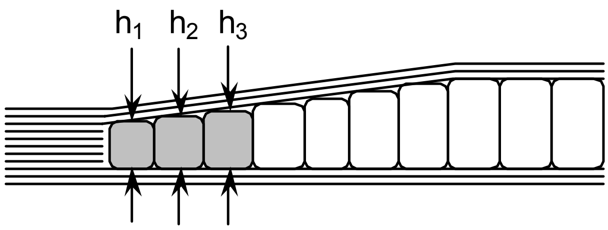

Fig. 7. Area of Sealant on Tapering Edge Strengthening for Flat Sandwich Panel

Average edge depth, h:

$$h = \frac{h_1 + h_2 + h_3}{3} \tag{15}$$

Sealant weight for honeycomb core tapering edge strengthening can be estimated from:

$$W_{ES} = Lh(3D_C)\rho_{ES} \tag{16}$$

where L = perimeter of honeycomb

D_C = diameter of the cell (i.e. 3.2mm)

3.2 Sandwich Flat Panel (Full Honeycomb Core)

Sandwich flat panel in this category is referring to floor panel and airstair tread. Weight estimation of this type of sandwich panel includes face sheets (carbon and glass fibre), core, film adhesive and paint.

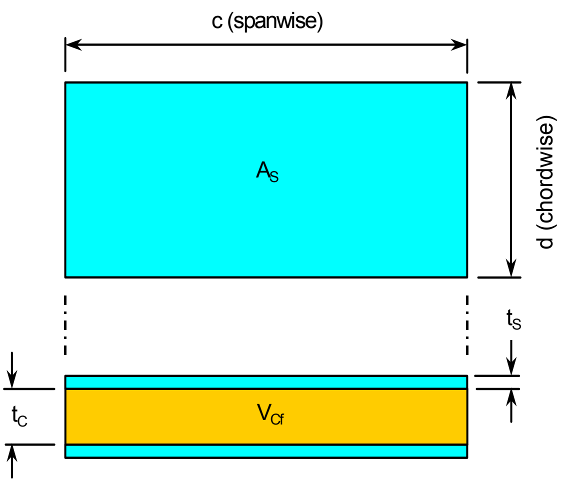

Fig. 8. Geometry of Honeycomb Core Sandwich Flat Panel

Area of skin, A_S:

$$A_S = cd \tag{17}$$

Volume of flat panel honeycomb core, V_{Cf}:

$$V_{Cf} = cdt_c \tag{18}$$

Weight for sandwich flat panel with full honeycomb core can be estimated as:

$$W_{SFP} = 2[A_S W_C]n + 2[A_s W_G]n + V_{Cf}\rho_C + 2A_S W_{FA} + 2A_S W_P \tag{19}$$

3.3 Sandwich Flat Panel (Honeycomb Core with Tapering on Edge)

This category of sandwich panel usually is referring to access panel on relatively flat skin contour. Its configurations are similar to full honeycomb core sandwich flat panel except it has core tapering towards the edge of the panel.

Depends on the geometry constrain of the core where few layers of the film adhesive might be used. This is to stabilize the core and minimize the possibility of core crushing during debulking and panel curing.

Honeycomb core tapering base length, S:

$$S = \frac{t_c}{\tan\theta} \tag{20}$$

Honeycomb core tapering length, S_t:

$$S_t = \frac{t_c}{\sin\theta} \tag{21}$$

Top surface area of honeycomb core (trapezoid), A_1 and A_3:

$$A_1 = A_3 = \frac{1}{2}(d_1 + v)S_t \tag{22}$$

Top surface area of honeycomb core (trapezoid), A_2 and A_4:

$$A_2 = A_4 = \frac{1}{2}(j + u)S_t \tag{23}$$

Top surface area of honeycomb core (rectangular), A_5:

$$A_5 = uv \tag{24}$$

Bottom surface area of honeycomb core (rectangular), A_6:

$$A_6 = jd_1 \tag{25}$$

Total surface area of honeycomb core, A_{Ct}:

$$A_{Ct} = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 \tag{26}$$

Chordwise edge surface area of panel (rectangular), A_{ec1}:

$$A_{ec1} = d_1 c_1 \tag{27}$$

Chordwise edge surface area of panel (rectangular), A_{ec2}:

$$A_{ec2} = d_1 c_2 \tag{28}$$

Spanwise edge surface area of panel (rectangular), A_{es1}:

$$A_{es1} = cd_2 \tag{29}$$

Spanwise edge surface area of panel (rectangular), A_{es2}:

$$A_{es2} = cd_3 \tag{30}$$

Total inner surface area of panel, A_{Si}:

$$A_{Si} = A_{Ct} + A_{ec1} + A_{ec2} + A_{es1} + A_{es2} \tag{31}$$

Total outer surface area of panel, A_{So}:

$$A_{So} = cd \tag{32}$$

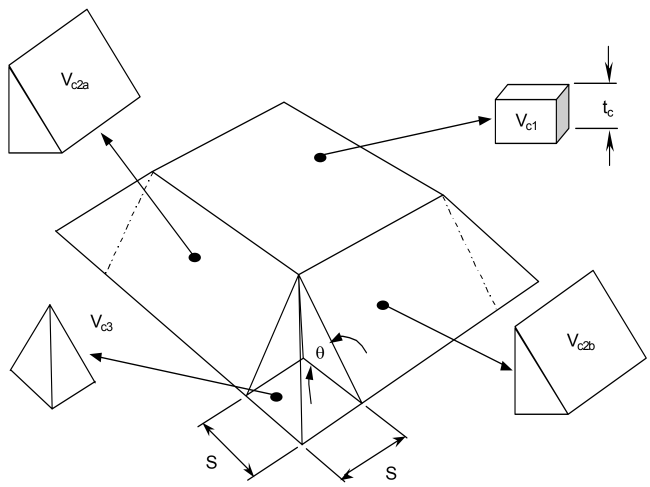

Fig. 9. Geometry of Honeycomb Core

Volume of honeycomb core on section 1, V_{C1}:

$$V_{C1} = t_c uv \tag{33}$$

Volume of honeycomb core on section 2a, V_{C2a}:

$$V_{C2a} = 2\left[\frac{1}{2} t_c S v\right] \tag{34}$$

Volume of honeycomb core on section 2b, V_{C2b}:

$$V_{C2b} = 2\left[\frac{1}{2} t_c S u\right] \tag{35}$$

Volume of honeycomb core on section 3, V_{C3}:

$$V_{C3} = 4\left[\frac{1}{3} S^2 t_c\right] \tag{36}$$

Total volume of honeycomb core, V_{Ct}:

$$V_{Ct} = V_{C1} + V_{C2a} + V_{C2b} + V_{C3} \tag{37}$$

Weight for sandwich flat panel with honeycomb core tapering on edge can be estimated as:

$$W_{SFP} = [A_{Si} W_C]n + [A_{So} W_C]n + V_{Ct}\rho_C + [A_{Ct} W_{FA}]n + [A_{Si} + A_{So}]W_P \tag{38}$$

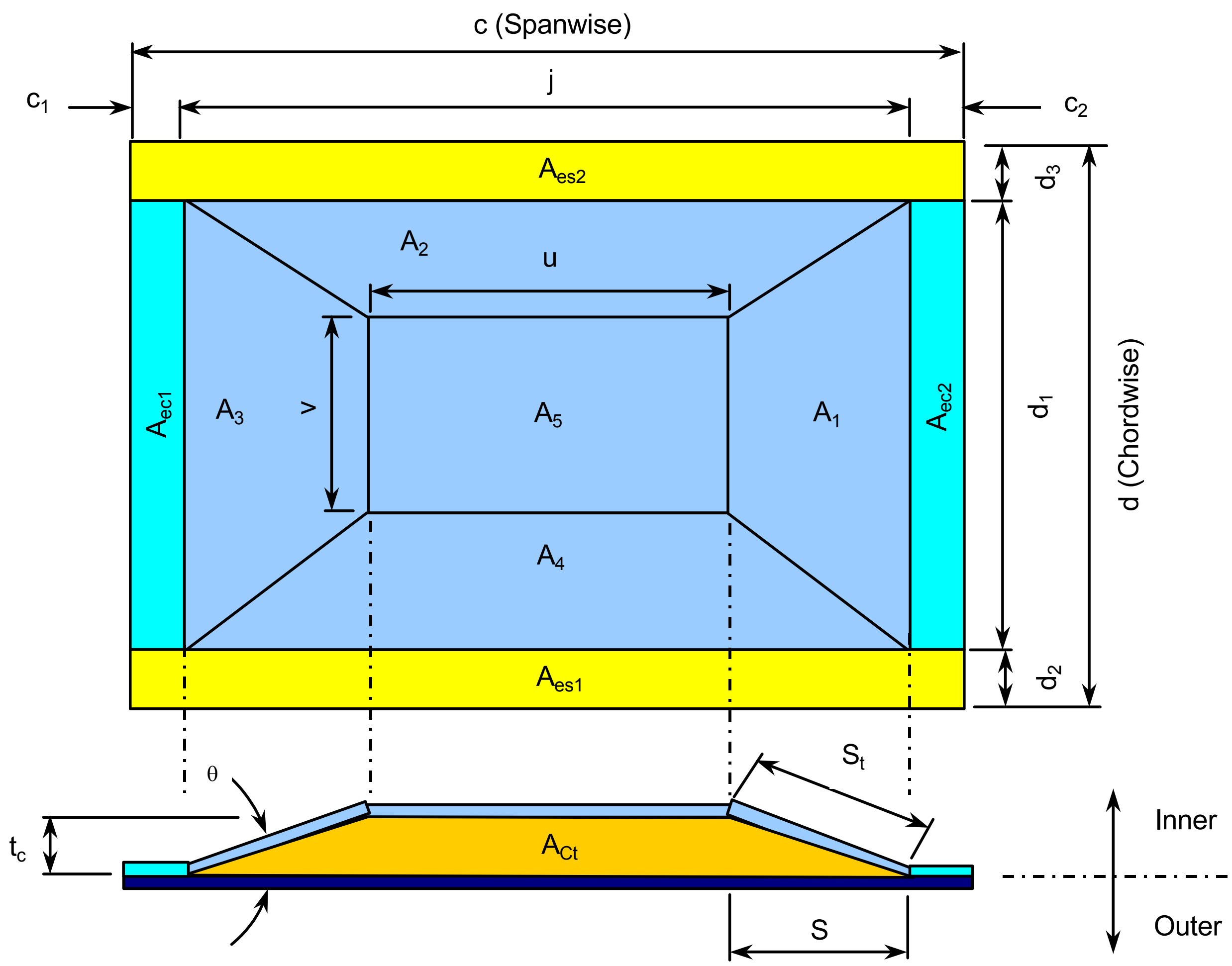

Fig. 10. Geometry of Honeycomb Core Sandwich Flat Panel with Tapering on Edge

3.4 Sandwich Flat Panel (Multiple Foam Core)

This category of sandwich panel is same as honeycomb core configuration but it is replace with multiple chunk of foam cores to further lighten the structure. In this configuration, film adhesive is not needed.

The derivation of properties for the foam core is similar to honeycomb core. Therefore, equation 20 through 26 and 33 through 37 from section 3.3 is referred in here for the calculations of foam core properties, except where t_c is being replaced with t_f (thickness of foam), A_{Ct} is being replace with A_{Ft} (total surface of foam core) and V_{Ct} is being replaced with V_{Ft} (total volume of foam core).

Similarly, the properties of the panel surface area can be referred from section 3.3 on equation 27 through 30 except the middle surface area, A_m needs to be establish as below.

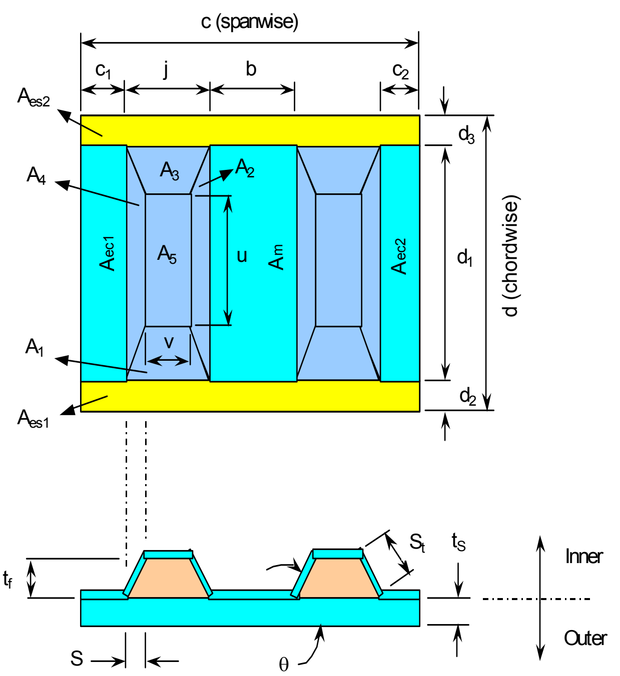

Fig. 11. Geometry of Sandwich Flat Panel with Multiple Foam Core

Middle surface area of panel (rectangular), A_m:

$$A_m = bd_1 \tag{39}$$

Total inner surface area of panel, A_{Si}:

$$A_{Si} = A_{Ft} + A_{ec1} + A_{ec2} + A_{es1} + A_{es2} + A_m \tag{40}$$

Total outer surface area of panel, A_{So}:

$$A_{So} = cd \tag{41}$$

Weight for sandwich flat panel with multiple foam cores can be estimated as:

$$W_{SFP} = [A_{Si}W_C]n + [A_{So}W_C]n + V_{Ct}\rho_C + [A_{Ct}W_{FA}]n + [A_{Si} + A_{So}]W_P \tag{42}$$

3.5 Monolithic Flat Panel

It is used where strength is required in a secondary structure. These are spoiler and less critical high lift devices. Its configurations are relatively similar to flat panel except the honeycomb core has being replaced by full solid laminates plies. Film adhesive is being eliminated from this configuration since there are no bonding in between honeycomb core and plies in this case.

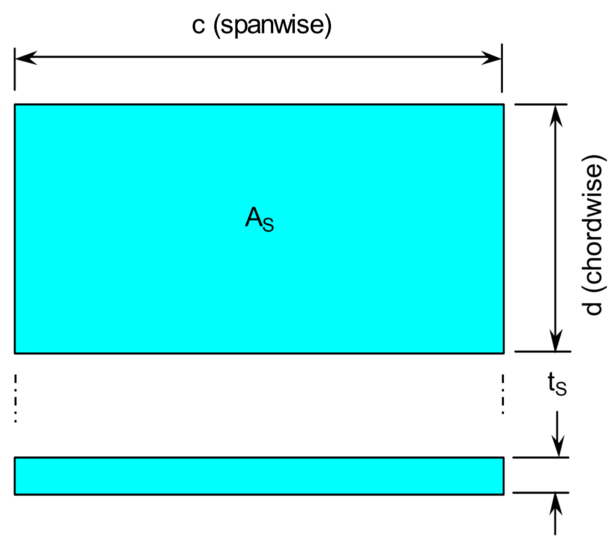

Fig. 12. Geometry of Monolithic Flat Panel

Area of skin, A_S:

$$A_S = cd \tag{43}$$

Weight for solid laminate flat plate can be estimated as:

$$W_{SL} = 2[A_S W_C]n + 2A_S W_P \quad (44)$$

3.6 Solid Laminate Integrally Stiffened Flat Panel

It is used where strength is required in a secondary structure. These are spoiler and less critical high lift devices. Its configurations are relatively similar to flat panel except the honeycomb core has being replaced by full solid laminates plies. Film adhesive is being eliminated from this configuration since there is no bonding in between honeycomb core and plies in this case.

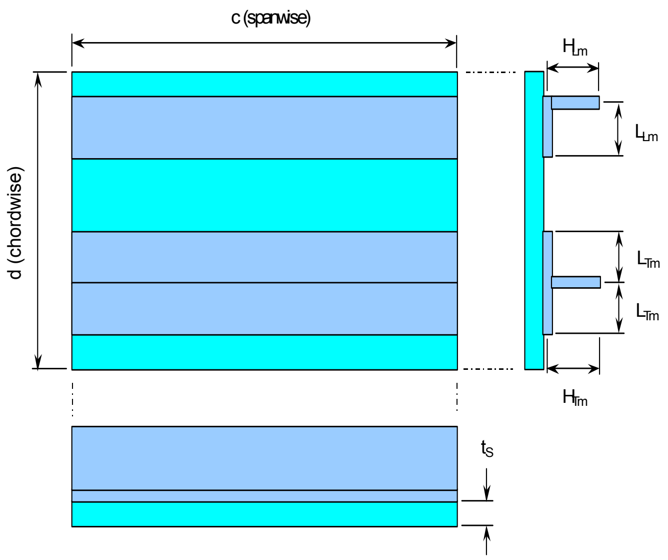

Fig. 13. Geometry of Solid Laminate Stiffened Flat Panel with L and T Section

Area of skin, A_S:

$$A_S = cd \quad (45)$$

Surface area of L section, A_{SL}:

$$A_{SL} = L_{Lm}c + H_{Lm}c \quad (46)$$

where L_{Lm} is the mean base length and H_{Lm} is the mean height of section L

Surface area of T section, A_{ST}:

$$A_{ST} = 2[L_{Tm}c + H_{Tm}c] \quad (47)$$

where L_{Tm} is the mean base length and H_{Tm} is the mean height of section T

Weight for solid laminate integrally stiffened flat plate with L section can be estimated as (presumed co-cure):

$$W_{SL} = 2[A_S W_C]n + A_S W_P + [A_S - NL_{Lm}c]W_P + [A_{SL} W_C]n + A_{SL} W_P \quad (48)$$

Weight for solid laminate integrally stiffened flat plate with T section can be estimated as (presumed co-cure):

$$W_{SL} = 2[A_S W_C]n + A_S W_P + [A_S - 2NL_{Tm}c]W_P + [A_{ST} W_C]n + A_{ST} W_P \quad (49)$$

3.7 Sandwich Curve Panel

It is the most widely used panel in aircraft structure. This category of sandwich panel usually used as commercial aircraft engine cowling, pressures relieve door and main landing gear door. It is similar to sandwich flat panel with tapering of core on the edge except it is in curve shape. Generally this category of sandwich panels is associated with thick cores. Therefore, few layers of film adhesive will be used in order to stabilize the core during panel curing process.

It is assumed that the corners of the curve honeycomb core are resemblance of the pyramid.

Honeycomb core tapering base length, S:

$$S = \frac{t_c}{\tan\theta} \quad (50)$$

Honeycomb core tapering length, S_t:

$$S_t = \frac{t_c}{\sin\theta} \quad (51)$$

Top surface area of honeycomb core (trapezoid), A_a and A_c:

$$A_a = A_c = \frac{1}{2}(o+z)S_t \quad (52)$$

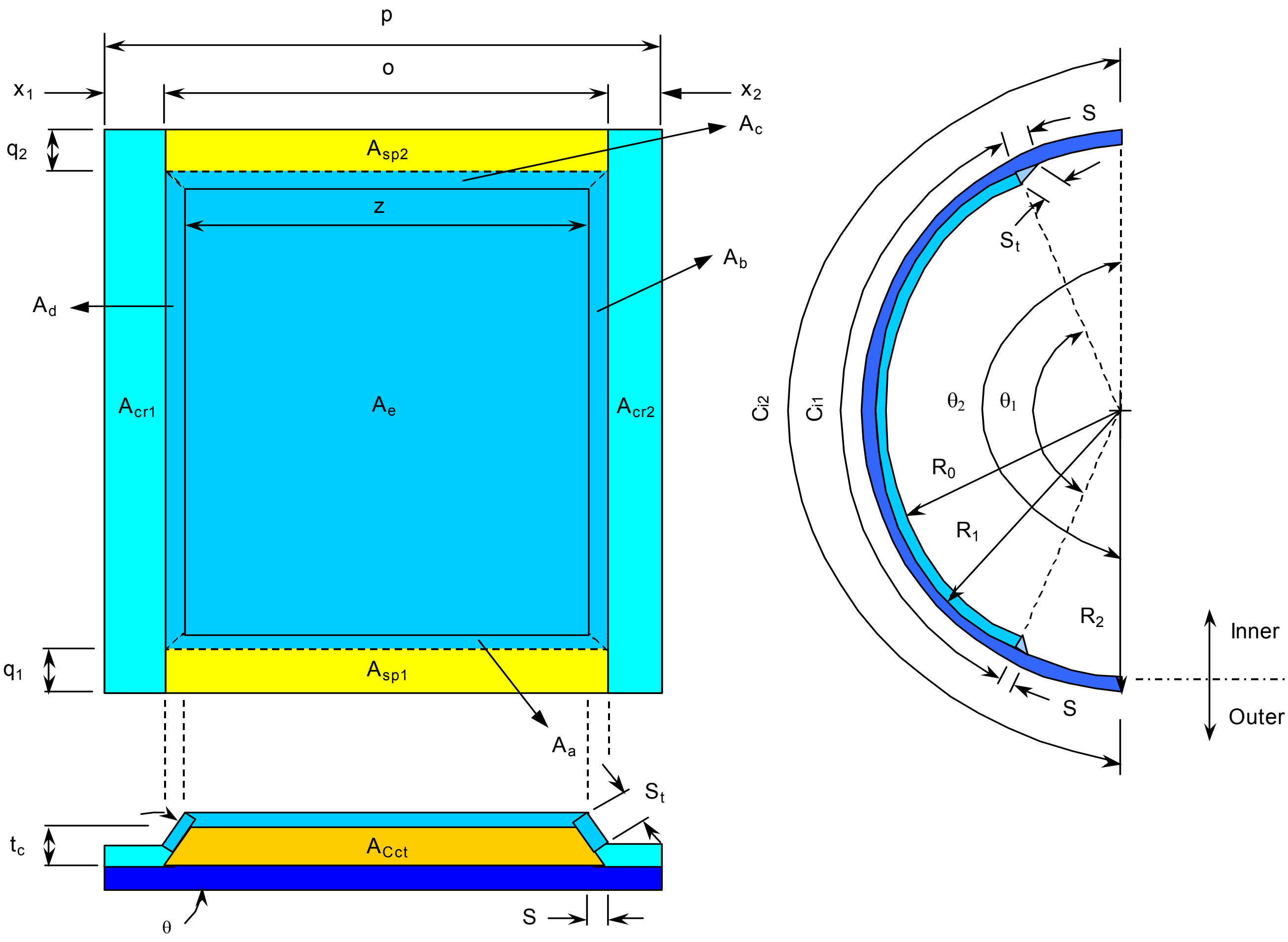

Fig. 14. Geometry of Honeycomb Core Sandwich Curve Panel with Tapering on Edge

Top surface area of honeycomb core (trapezoid), A_b and A_d:

$$A_b = A_d = \frac{1}{2}[(C_{i1} + 2S) + C_{i1}]S_t \tag{53}$$

where C_{i1} *is the circumference of outer curve &*
$C_{i1} = R_1\theta_1$
Note : θ *is in radians*

Top surface area of honeycomb core (rectangular), A_e:

$$A_e = C_{i1}o \tag{54}$$

Bottom surface area of honeycomb core (rectangular), A_f:

$$A_f = (C_{i1} + 2S)o \tag{55}$$

Total surface area of honeycomb core, A_{Ct}:

$$A_{Ct} = A_a + A_b + A_c + A_d + A_e + A_f \tag{56}$$

Curvature surface area of curve panel, A_{cr1}:

$$A_{cr1} = C_{i2}x_1 \tag{57}$$

Curvature surface area of curve panel, A_{cr2}:

$$A_{cr2} = C_{i2}x_2 \tag{58}$$

Edge strip surface area of curve panel, A_{sp1}:

$$A_{sp1} = oq_1 \tag{59}$$

Edge strip surface area of curve panel, A_{sp2}:

$$A_{sp2} = oq_2 \tag{60}$$

Total inner surface area of curve panel, A_{Si}:

$$A_{Si} = A_{Ct} + A_{cr1} + A_{cr2} + A_{sp1} + A_{sp2} \tag{61}$$

Total outer surface area of curve panel, A_{So}:

$$A_{So} = C_{i2}p \tag{59}$$

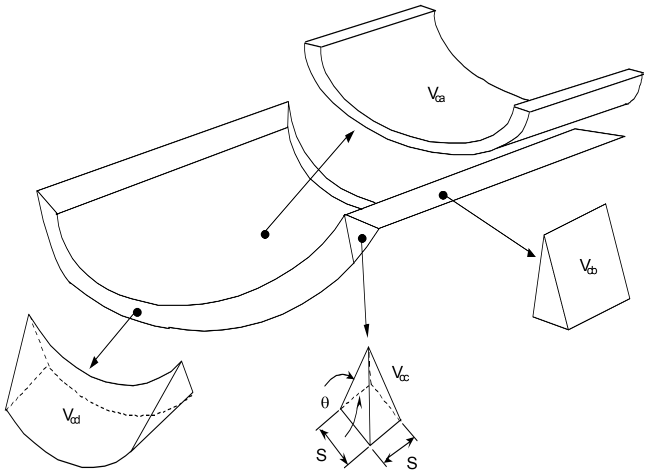

Fig. 15. Geometry of Honeycomb Core in Curve Panel

Volume of honeycomb core on section a, V_{ca}:

$$V_{ca} = \left[\left(R_1^2 - R_0^2\right)\theta_1\right]z \tag{62}$$

Volume of honeycomb core on section b, V_{cb}:

$$V_{cb} = 2\left[\frac{1}{2}t_c Sz\right] \tag{63}$$

Volume of honeycomb core on section c, V_{cc}:

$$V_{cc} = 4\left[\frac{1}{3}S^2 t_c\right] \tag{64}$$

Volume of honeycomb core on section d, V_{cd}:

$$V_{cd} = 2\left[\frac{1}{2}St_c C_{i1}\right] \tag{65}$$

Total volume of honeycomb core, V_{Ct}:

$$V_{Ct} = V_{ca} + V_{cb} + V_{cc} + V_{cd} \tag{66}$$

Weight for sandwich flat panel with honeycomb core tapering on edge can be estimated as:

$$W_{SFP} = [A_{Si}W_C]n + [A_{So}W_C]n + V_{Ct}\rho_C + [A_{Ct}W_{FA}]n + [A_{Si} + A_{So}]W_P \tag{67}$$

4 Conclusion

The breakdown of the composite secondary structure to various geometries can be effectively used by the weights engineer to make preliminary weight estimates and conduct trade studies on various sizing and manufacturing methods.

The weight engineer should be aware that there are other factors that might affect the weight estimation of composite secondary structure based on geometries breakdown. These are illegal geometries definitions, complex curvature and surface waviness.

Despite this, the weight of the structure can be estimated by using the standard geometry functions. It is estimates that, the deviation of weight is very minimum in between the illegal geometry and standard geometry.

The used of geometries breakdown analysis techniques towards composite secondary structure weight estimation during conceptual and preliminary design stage, is crucial to the program and also as a counter measure of cost-effective achievement.

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