13

Skirt design

13.1 Introduction

Skirt service life is an important factor in the successful application of hovercraft and their credibility for users. At the early stage of hovercraft development, skirt life was as low as several hours of craft operation. The first task for the members of the trials team of the Chinese test craft model 711-II after tests was repair of the flexible skirt damage before testing on the next day.

Twice in a month, tearing of the bow bag occurred to the SES model 719 weighing 70 t, which not only cost a large amount of labour and money and affected the credibility of ACV/SES, but also caused great inconvenience for the users when looking for a dock to undertake the skirt repair. This caused the ferry operators to refuse to use the hovercraft because of lack of skirt repair facilities.

Such problems are not normal for present-day ACV/SES. Bag and loop components generally last many thousands of hours with general wear and tear, while segments and fingers may be left in place for up to 1500 hours operation before replacing the lower half only. It is nevertheless important that segment tip wear is monitored, since uneven wear can cause a significant increase in skirt drag and thus loss of performance. Luckily segment damage is visible as increased spray while hovering over water, and so can easily be observed.

A review of the types of wear and damage experienced is presented below to assist designers to minimize the sensitivity of a given skirt to the causes, so improving operational life.

13.2 Skirt damage patterns

There are many patterns of damage to skirts, which can be summarized as follows.

Delamination

The delamination of outer/inner rubber coating from the nylon fabric, which leads to water ingress to the fabric, decreasing its strength and accelerating damage.

Abrasion and corrosion

During the operation of ACV/SES, the skirt materials are abraded with sea-water, sand, stones and concrete, which cause the fabric to wear and sea-water to be taken into the fabric, as well as delamination and corrosion of the elastomer.

Tearing

In general, nylon fabric possesses higher tension strength but unsatisfactory tearing strength (*see* Table 13.2). This is because tension will be borne uniformly by the fibres of cloth layers, but during tearing of the fabric, the high concentrated load will cause the fibre of cloths to be broken layer after layer. For this reason, the most significant skirt damage, particularly of skirt bags, will be caused by the unsatisfactory tearing strength of the fabric. Thus designers have to pay great attention on this point to the stress concentration.

The principal failure pattern of skirts and its related major factors are listed in Fig. 13.1. It can be seen that three patterns of skirt damage, i.e. delamination, abrasion and tearing of the skirt fabric are each closely related to the operational environment, the fabric coating of rubber, the weave method of the nylon fabric and the joining of skirt cloths, therefore designers have to pay attention to the selection of skirt fabric, coating and the joining method of skirt cloths during design. These subjects we will introduce in the next section.

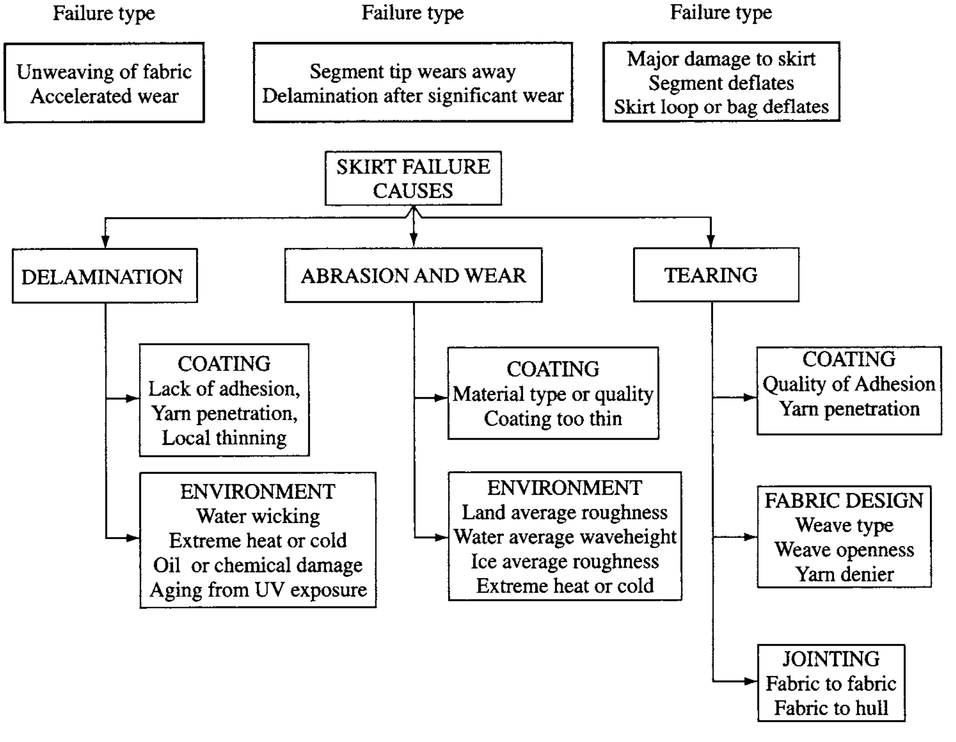

Fig. 13.1 Factors affecting the three modes of skirt damage.

13.3 Skirt failure modes

The actual failure modes of skirts from craft in operation can be found listed in Table 13.1 and may be summarized as follows:

1. So far as the small and medium-size ACV/SES are concerned, tearing of the skirt bag will seldom occur, because of the favourable operational environment and satisfactory skirt material for such craft.
2. With respect to the ACV/SES of medium and large size, tearing of the skirt bag will still be a serious problem, particularly for larger SES, because repair of the skirt bag will have to be carried out in dock or floating dock, which will cost a large amount of money. Therefore the improvement of skirt bag life is still a very important study theme for designers and skirt manufacturers. Rip stops are very helpful.
3. The upper and lower bag of the longitudinal stability trunks of ACVs will be easy to wear out or tear during landing or launch of the craft because of the craft trim.

Table 13.1 The failure mode of hovercraft skirts

Craft	Skirt outer loop or bag	Stability trunks	Bow finger	Side finger	Stern bags
SR.N4	Occasional tearing	Occasional tearing	Delamination Abrasion Fabric wrinkle and wear	Abrasion Fabric wear Delamination Tearing	Abrasion Fabric wear
Voyageur Coastguard	Tearing	Abrasion Tearing	Delamination Abrasion Fabric wear	Tearing Abrasion Fabric wear Joint crimp	Abrasion Fabric wear
SES–100B	Joint wear Seam delamination Rubber breakdown	N/A	Flagellation Abrasion Rubber breakdown	N/A	No damage
Voyageur Arctic Ops	Tearing Rubber breakdown	Tearing	Abrasion Tearing Finger tearing and detachment	Abrasion Tearing Finger tearing and detachment	Abrasion Conical bag tearing and detachment
722-I ACV	Tearing	Abrasion Tearing at stern	Delamination Fabric wear Crimp	Finger tearing and detachment Delamination caused bag tearing	Tearing and abrasion at stern corner Fabric wear
719-G SES	Tearing	N/A	Delamination Fabric wear Crimp	N/A	Fabric wear Tearing
7203 SES	Finger life longer than 600 hours	N/A	Delamination Fabric wear Crimp	N/A	Life longer than 600 hours for lower bag
7202 ACV	Tearing	Abrasion Tearing	Delamination Fabric wear	Abrasion Tearing over ice	Abrasion Tearing over ice

For this reason, great attention has to be paid during the installation of the trunk. It is suggested that too low installation of such a trunk is unsuitable. Moreover, repair of the stability trunk is particularly difficult unless there is a facility to lift the craft. This is the one reason for JEFF(A) to replace the bag and inner skirt with the peripheral cell so as to eliminate the stability trunks.

4. The abrasion, delamination and wrinkling of flexible inner membranes often occur to bow and side skirts. Fortunately, local damage of the skirt finger probably does not substantially affect the performance of the craft. For example, the operational time and range for some Chinese SES are as long as to 1000–2000 hours and 40 000–90 000 km respectively, with several finger/lower bags damaged, but still in operation. They can be replaced by fixed time duration maintenance, or by underwater replacements (for SES).
5. At the stern, particularly at the stern corners, owing to the water scooping of skirts of poor design, the skirt fingers or lower bags of the skirt at this part are often damaged. We obtained test results for the force acting on the attachment bolts joining the rear part of the skirt fingers with the bag of an ACV weighing 70 t. It showed about 4.8–9.8 kN of impact force acting on one bolt. It seems that it would damage the skirt bag in the case where the bolts were connected to the skirt bag. Figure 13.2 shows the inner and outer connection of a typical skirt finger and its components.
6. The skirt fingers and stern lower bag are easy to tear or wear when operating ACVs on ice. Therefore this is also a serious problem faced by designers. Use of inner drape membranes and sacrificial elements can reduce this problem.

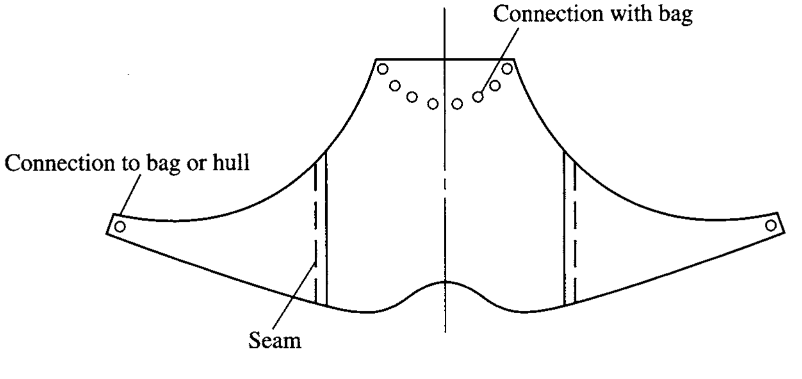

Fig. 13.2 Development of a typical skirt fingers and attachments.

13.4 Skirt loading

The loads acting on skirts are shown in Fig. 13.3. We summarize these below.

Pressure force

This includes static and dynamic pressure forces as well as the impact pressure force due to the action of waves and heave/pitch motion. Some data suggest that the impacting pressure is higher than static pressure by up to 8–10 times. However, this impacting pressure is supported by the tension of the skirt membrane. The skirt material deflects locally in response to impact, so damping out the pressure transients.

Vibration forces

This includes the fluttering and flagellation forces. The first is often associated directly with the high-frequency vibration of the edge of the fingers themselves, due to air escaping past them, which produces low stress but very high strain rates in the coating material and is accompanied by heat build-up due to coating hysteresis and friction between the fabric fibres, therefore the flagellation causes the finger damage.

The flagellation is associated with the contact of a finger edge with either a wave or some obstacles on land. The resulting spring-back and low-frequency oscillation of the finger, due to the pressure forces driving it back into an equilibrium position, provide stresses and moments which are sufficient to cause material degradation and failure. When a coated fabric is subjected to cyclic vibration of stress or strain, a certain proportion of the input deformation energy is non-recoverable. The non-recovered energy, termed the hysteresis loss, has in general four components:

1. internal losses in the fibres;
2. internal losses in elastomer coating;
3. frictional losses associated with relative movement at fibre-to-fibre contact point;
4. frictional losses at the fabric/elastomer interference.

All these energy losses convert to heat, because of the low thermal conductivity of rubber, and the heat at the coating/fabric interface at the finger tip is not readily

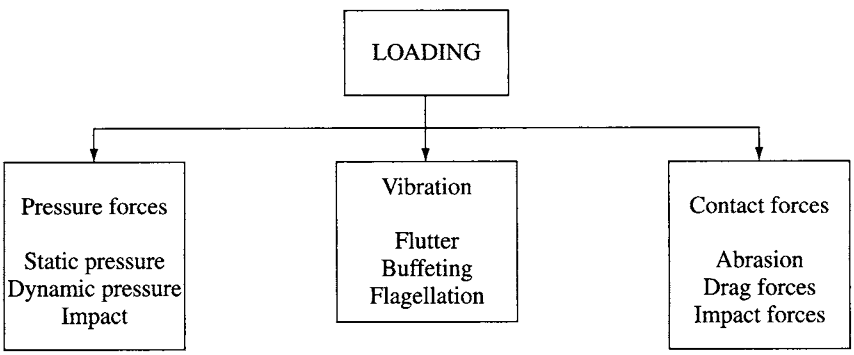

Fig. 13.3 Loads acting on skirts.

dissipated, resulting in a rise in internal temperature and corresponding deterioration of tensile and/or adhesion strength of the coating.

The internal temperature of a specimen rose rapidly and could be measured at 150 °F at the highest frequency of 17.5 Hz as shown in Fig. 13.4 [99] which shows the acceleration and internal temperatures of the flagellation test specimen. The experiment [99] showed that the fatigue life of a test specimen of coating fabric will be decreased to 10% when the temperature increased from 38 to 54 °C, and fatigue life will be decreased to 1% when the temperature increased from 38 to 57.5 °C. The high acceleration and high temperature during the high-frequency vibration of the fabric specimen are the main causes of the damage of the lower edge of the skirt fingers.

Since the life of a skirt finger decreases rapidly due to the high acceleration and high temperature during the vibration of skirt fingers at high frequency, it will therefore deteriorate as the craft weight increases with craft speed, because the velocity of air leakage will be increased with the craft weight and speed. From Fig. 13.5, one can see that the skirt life will decrease to 10% as the craft speed doubles.

Elastomer or rubber delamination caused by high-frequency vibration is the main cause of skirt finger damage. In order to study the loads experienced and to predict skirt life, research institutes and other organizations associated with ACV/SES are

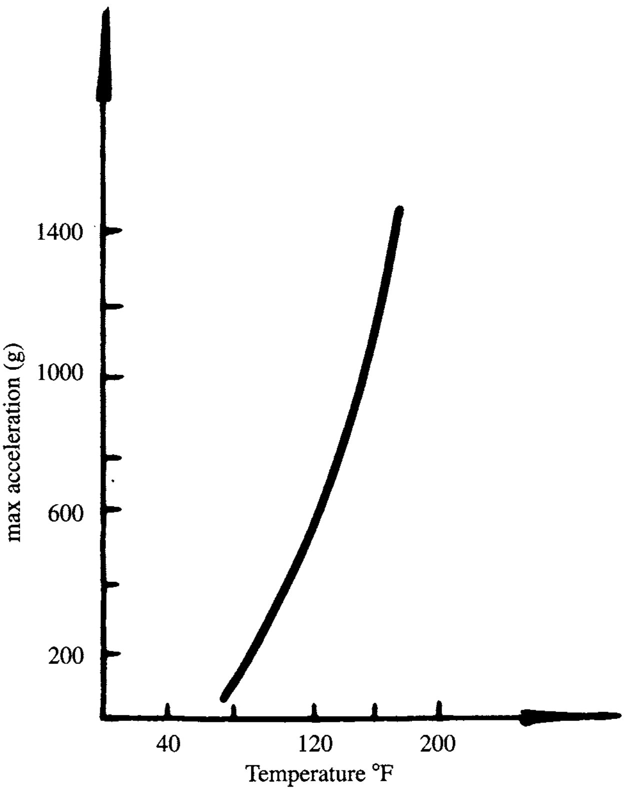

Fig. 13.4 (a) Relations between various parameters in case of vibration on the tip of skirt fingers: (a) relation between the maximum acceleration on tips of skirt fingers and flow rate

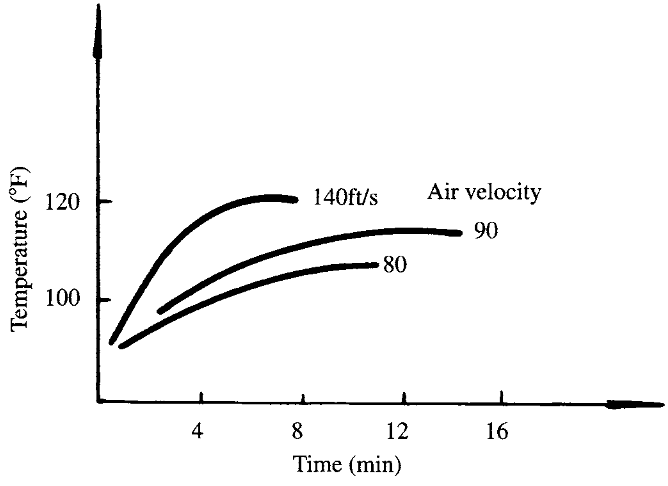

Fig. 13.4 (b) Relation between the temperature rise of fingers and flow rate.

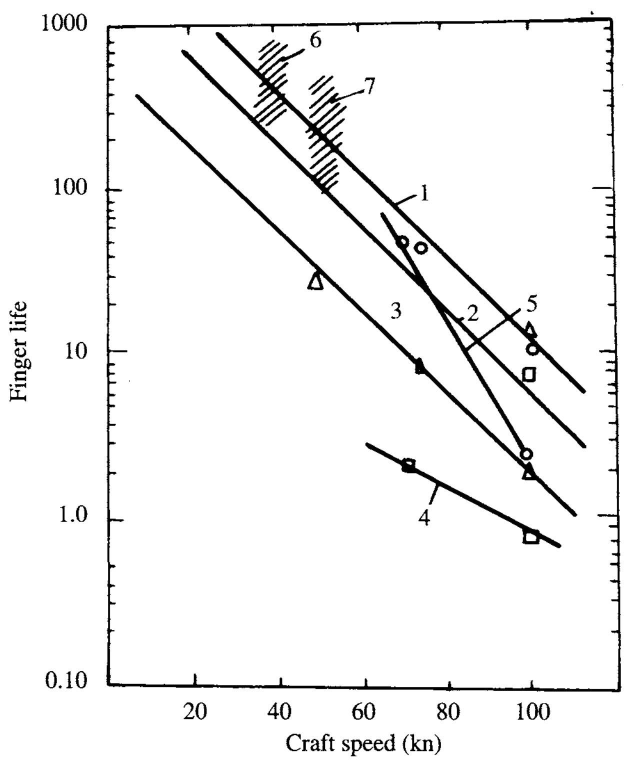

Fig. 13.5 Relation between the finger life, ship speed and the coating of skirts. 1: natural rubber 2.48 kg/m^2; 2: neoprene 3.37 kg/m^2; 3: neoprene 2.5 kg/m^2; 4: neoprene 1.63 kg/m^2; 5: neoprene 2.21 kg/m^2; 6: VT–1 1.36 kg/m^2; 7: SRN–4 4.76 kg/m^2.

making great efforts to study this area and provide various experimental facilities as follows:

1. 'flutter' test facility,
2. 'flagellation' test facility;
3. skirt test facility for water-jet impact testing;
4. abrasion tests for skirt finger materials;
5. fatigue tests due to the vibration of skirt joint, etc.

Figure 13.6 shows the kind of tests that can be carried out using skirt material samples, and air or water jets to create the vibrational loadings.

Some experts consider [4] that the best way to test the skirt material is by use of large scale self-propelled models or the full scale sections of skirt. The small-scale test facilities listed above can identify or quantify the main parameters in skirt wear,

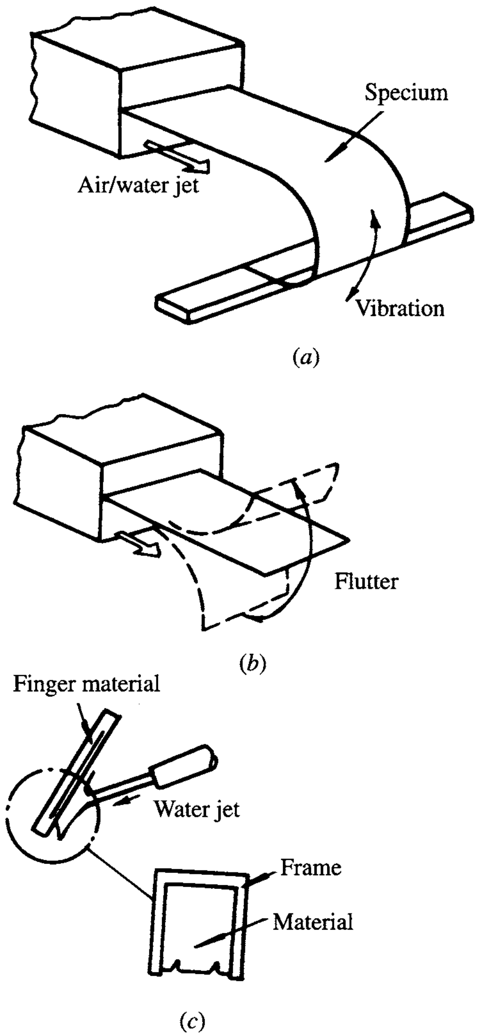

Fig. 13.6 Test facilities for skirt materials. (a) vibration, (b) flutter, (c) impact.

allowing service life predictions to be made or design modifications to be proposed; nevertheless, unless some full-scale service data are logged, even full-scale tests can only approximate the expected life. An integrated approach is therefore needed if skirt segment lives are to be improved from the current norms listed earlier in this chapter.

13.5 Contact forces

In this respect, there are three forces as follows.

Abrasion force

This is the friction of the skirt fingers (and stern lower bag or loop) with sand, concrete and ice. With respect to the passenger ACVs operating in the English Channel, e.g. SR.N4, the wearing out of skirt fingers mainly comes from the direct contact of skirt finger material with the sand and concrete.

In addition, the metal joints connecting the bag with fingers, bag with hull structure and so on (as bolts had been widely used on ACV/SES in the early stage of hovercraft research in China) often cause self-damage of skirt material due to the internal abrasion between the hard metal joints and flexible skirt material, particularly in the case of landing/launching of ACVs. This is an important reason causing short life of skirts in the case of poor design and assembly of the skirts.

Drag force

During hull-borne operation, the drag due to the skirt (particularly of the skirt bag) is large, and the drag force for hull-borne operation which is different from that for cushion-borne operation, is balanced by the tearing force of skirt cloths. The drag force for cushion-borne operation is balanced by the tension of skirt cloths,

The tearing strength of skirt cloths is far lower than the tension strength of skirt cloths, therefore towing operations of hovercraft hull-borne for a long time should be avoided; for example, the ACV model 716-II was towed hull-borne after the craft was launched, causing local tearing of the skirt to occur before it arrived at its destination.

Slamming, water scooping and plough-in may occur to a hovercraft in cushion-borne operation, particularly in rough seas. Skirt fingers may also be scooping water during the turning of hovercraft at high speed.

All such phenomena will lead to large instantaneous hydrodynamic forces so as to tear the skirt cloths or lead to tremendous bag pressure to burst the skirt bag and lead to plough-in. The SR.N4 hovercraft ferry tore a large split of 30 m in its bag while trying to go through the entrance to Dover harbour. Such a split with a large area also happened to the ACV 722-1 operating in waves at high speed. A split bow bag also occurred to model 711-II during plough-in tests. The stern bag of SES model 719 was also broken during craft take-off, caused by mud and rubbish filling the stern bag, causing very large hump drag.

Impact force

During operation of hovercraft, floating objects or obstacles are likely to be encountered, which will cause local impact; for example, during a landing operation of ACV 722–1 downwind, the craft was landing at high speed, the pilot was obliged to throttle down suddenly and caused the stern bag and stern longitudinal stability trunk to split. Such impact force is tremendous and large enough to destroy the skirt bag. However, the skirt can protect the hull.

Such force is difficult to estimate and simulate; it is exactly the main consideration of designers during the selection of materials and configuration of skirts. Figure 13.7 denotes the typical wreck mode of skirt fingers.

13.6 Selection of skirt material

The following issues have to be considered during selection of skirt materials:

1. tension strength of material;
2. tearing strength of material;
3. anti-delamination capability of coating fabric;
4. flexibility and anti-ageing capability of skirt cloths (nylon fabric coating);
5. the low temperature characteristic of skirt materials for situations where the craft are operating on ice.

The tensile strength of skirt cloths is dependent on the tension strength of the woven fibre, and is related to the specific weight of the fibre material. Generally speaking, the heavier the material the higher the tension strength as shown in Fig. 13.8. But tearing strength does not comply with this rule as shown in Fig. 13.8. A–G show the tearing strength of the samples made from various materials with different weaving

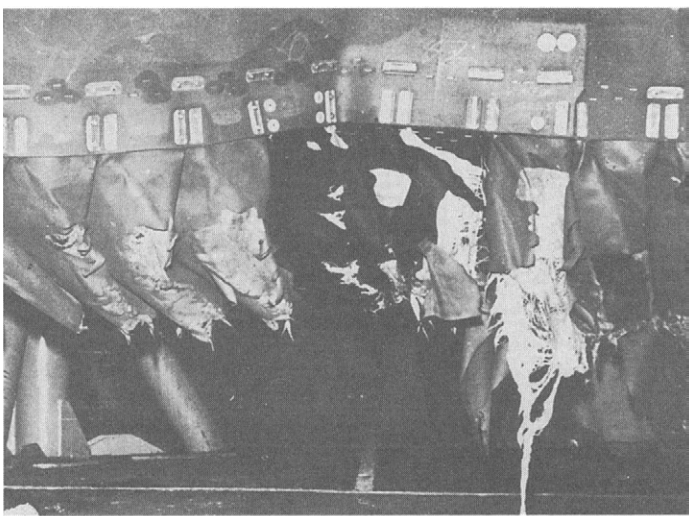

Fig. 13.7 Typical damage on skirt fingers.

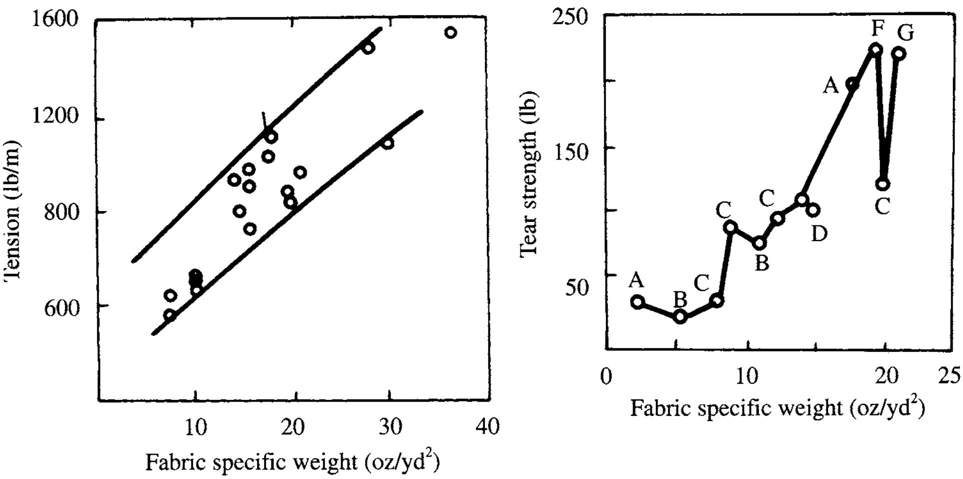

Fig. 13.8 Tension and tear strength of skirt materials.

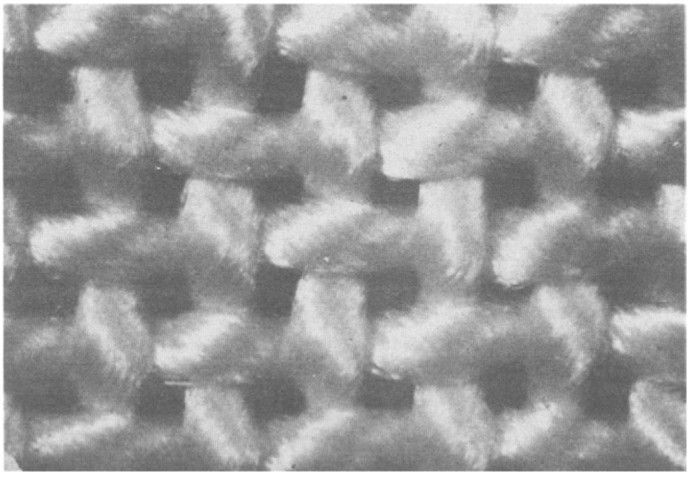

Fig. 13.9 Open weave skirt cloth.

methods. In general the fibres are twisted in ply to become the open weave as shown in Fig. 13.9. Thus the rubber coating actually will be adhesive, through the gap between both sides of the fabric; obviously the adhesive ability of open weave is higher than that on close weave, because the adhesive force between the rubber is larger than that between the fabric and rubber.

Open weave will not only improve the anti-delamination strength as mentioned above, but also increase the tearing strength of the fabric, because the ply twisted by the fabrics will have higher tension strength, thus improving its tearing strength, because the tension strength of skirt cloths is subject to the tension strength of all fibres per unit width of cloths, whereas the tearing strength of cloths is subject to the tension strength of unit fibre ply.

Table 13.2 Data for some skirt coating fabric produced in China [100]

Skirt fabric designation	Units	6408–1	57703
Width of coated fabric	mm	810	830–840
Thickness of coated fabric	mm	2	2.5
Specific weight of coated fabric	kg/m2	2.19	2.57
Peel strength – Original	N/ (5 cm)	660	980
Peel strength – 1 week's soak in fresh water	N/ (5 cm)	160	
Peel strength – 20 days' soak in fresh water	N/ (5 cm)	160	920
Peel strength – 1 week's soak in 10% salt water	N/ (5 cm)	350	
Peel strength – 20 days' soak in 10% salt water	N/ (5 cm)	260	
Breaking strength of coated fabric – warp	N/ (5 cm)	7100	4920
Breaking strength of coated fabric – weft	N/ (5 cm)	6270	6200
Tearing strength of coated fabric – warp	N	770	1490
Tearing strength of coated fabric – weft	N	910	1300
Application		Small and medium-size ACV or SES	Medium-size ACV and SES

Table 13.3 The coated fabric characteristics for Chinese and foreign ACV/SESs

Craft name		Craft weight (t)	Maximum craft speed (knots)	Cushion pressure (Pa)	Skirt height (m)	Coated fabric (kg/m^2)	Tension strength (N/cm^2)	Tear strength (N)	Skirt life (hours)	Notes
SR.N4	b	200	70	2521	2.4	2.9–4.6			5000 +	
Mk 2	f					4.5	8722	1875	100–400	
VT.1	b	110	46	2992	1.68	2.4	5690	893	5000 +	
	f					1.36			300–1200	
VT.2	b	106	60	2900	1.68	2.44	5690	863	5000 +	
	f					1.36			300–1000	
SR.N6	b	10.8	54	1256	1.22	1.36				
Mk.1	f					3.0	5690	893	200–750	
HM.216	b	20	35		1.0	3.0			2000 +	
	f					1.2		893	300–1500	
BH.110	b	138	35							
	f								700	
7202		2.8	24	981	0.5	1.5	2943	932	300	58021 fabric
711-1I		5.0	52	1170	0.75	2.1	5886	883	250	6408 fabric
716		15.0	50	1471	1.0	2.1	5886	883		6408 fabric
722-I		65.0	50	2453	1.6	2.6	4905	1177		57911 fabric

b = bag, f = finger.

The quality of Chinese skirt coating fabric has been dramatically improved, the data of some of which are shown in Table 13.2. Table 13.3 shows the characteristics of some coating fabric applied to foreign and Chinese ACV/SES. Fortunately thanks to the adoption of adhesives for joining the coating fabric, the joint strength has been greatly improved so that bolts and even more the stitching thread for joining seams of coating fabric does not have to be used, because bolts destroy the strength of the coating fabric and the joining strength of the latter is unsatisfactory. It should be noted here that for smaller amphibious ACVs, skirt materials used are light enough that stitched seams are adequate and are less expensive as an assembly method than glued or welded joints.

With respect to the coating, in general, natural rubber or neoprene are the most commonly adopted materials. The former is soft, elastic and has good resistance to delamination, so some ACV/SES manufacturers use natural rubber (at high cost) as the material for the bow fingers. On the other hand neoprene has outstanding resistance to wear and fine low-temperature performance. In China neoprene mixed with natural rubber is generally used as the coating material giving a good low temperature performance.

During selection of skirt material, the following aspects have to be considered. Different material should be applied to different locations. In general, the material for the skirt bag should have high tearing and tension strength, but not with good abrasion characteristics. For this reason, the fabrics of skirt bags should be of good strength and thin coating thickness. The fabric for fingers should be of low stiffness, but with a thick coating for larger commercial craft. Table 13.4 shows the specific weight of coating and nylon fabric for skirt fingers.

There are two points of view for the selection of skirt finger material: one is that the heavier material has to be chosen to meet the requirement of abrasion resistance; the other is that designers prefer to select material to reduce the inertia force acting on the skirt finger due to acceleration during skirts flutter, consequently preventing delamination of the elastomer, reducing the added resistance of craft in waves and so extending the skirt life. It is difficult to judge clearly which approach is correct, since the application itself has an influence. As far as air cushion ferries are concerned, since they often operate on sandy beaches, designers tend to specify a thicker coating in order to increase the abrasion resistance. With respect to military ACVs the speed performance and seaworthiness of craft are given higher priority than the abrasion quality of skirts, therefore the light-coated cloths will be better. Figure 13.5 shows the overall life of skirt fingers on ACV SR.N4 and VT.1.

Fig. 13.10 shows the relation between the specific weight of the bag–finger skirt of operated hovercraft and craft weight. It is very interesting that the points are not scattered, for this reason, ref. [4] suggested the expression as follows:

$$W_s = 15\ W^{0.333} \tag{13.1}$$

where W is the weight of craft (t) and W_s the skirt weight (oz/yd^2) (1 oz/yd^2 = 0.034 kg/m^2). The kinds of skirt material which can be selected by designers is rather limited. In general, there are three kinds of material to be adopted on ACV/SESs, i.e.

Table 13.4 The specific weight of skirt material for home and foreign ACVs

Craft	Country	Material location	Specific weight of coated fabric (kg/m^2)	Specific weight of nylon fabric (kg/m^2)
SR.N6	UK	Bag	1.36	0.407
		Finger	2.9–3.4	
SR.N4	UK	Bag	2.89	0.68
		Finger	4.6	
7202	China	Bag + finger	1.6	0.8
711 II	China	Bag + finger	2.1	

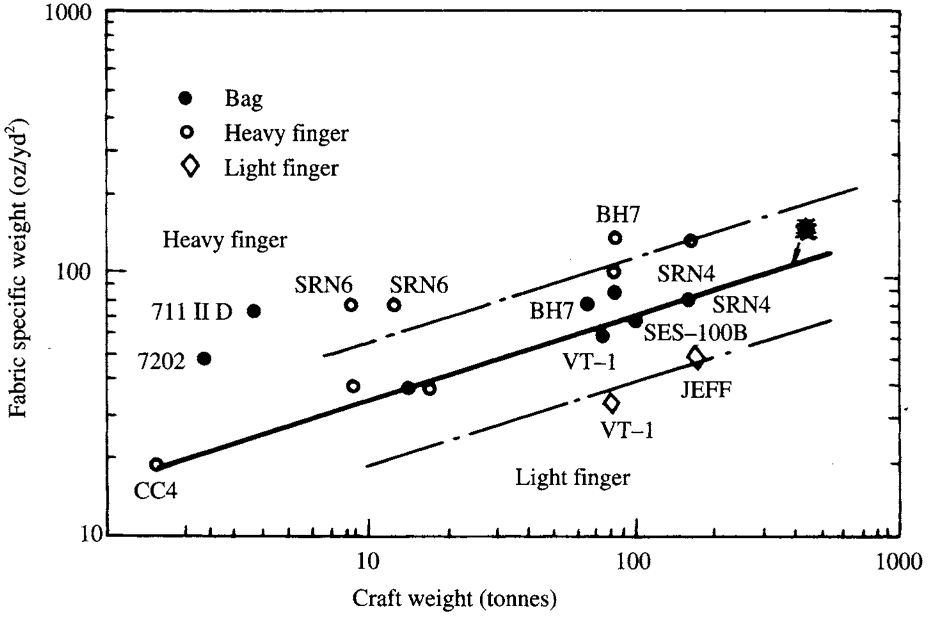

Fig. 13.10 Specific weight of skirt material and statistical relation with craft weight.

Mini ACV (or air cushion jeep),	W < 10 t	
Small ACV,	W = 10–30 t	(and SES)
Medium ACV,	W = 30–100 t	

In order to improve the strength of the skirt bag, it is suggested flexible stiffeners (rip stops) are used on the coating fabric. Thus it will increase the tension and tearing strength greatly and can also prevent the extension of splitting, which has been validated on the Chinese SES 719G, 719-II with good results.

Figure 13.11 shows the relation between the total weight of the skirt system and the

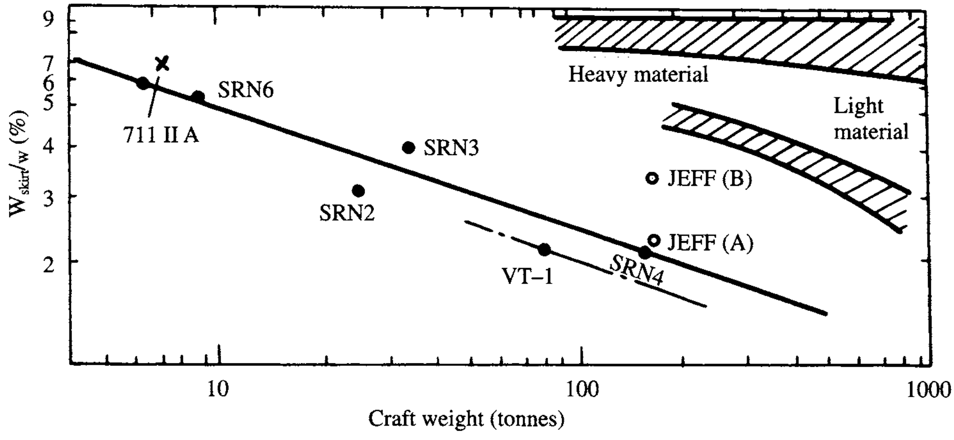

Fig. 13.11 Total weight of skirt system and relation to craft weight (hatched area denotes the material in research).

weight of the craft. Since the thickness of skirt material is impossible to increase with the linear dimension of the craft, therefore the proportion of skirt weight will decrease as size of craft increases.

13.7 Selection of skirt joints

The type of skirt joints is very important, because much skirt damage starts from the skirt joints, including those between the coating fabrics and the coating fabric and the hull. Therefore the requirements for the joints should be as follows:

1. High joining strength for joints themselves.
2. The joints should not injure the strength of coated fabric, otherwise the joints may be strong enough.
3. No self-damage will occur to the fabrics, owing to the flutter, flagellation and abrasion of skirts; so that the joints do not cause wear out or wrecking of the skirt fabric.
4. Light weight so that they do not cause corrosion or erosion of aluminium hull plates.

Table 13.5 lists and compares some typical joints, which are widely applied to Chinese and western hovercraft. Figures 13.12 and 13.13 show some types of skirt joints applied

Table 13.5 Comparison between the various joints (see also Figs 13.12 and 13.13)

Items	Name of joints	Placing	Merit	Limitations	Recent applications
1	Nylon thread	Coated fabric with coated fabric	Light	Low strength	Recreation craft
2	Belt bolts	Coated fabric with coated fabric, bag and finger	Cheaper	Poor anti-corrosion capability and also occasionally injures the skirt fabric	Obsolete
3	Steel bolts and washers	Bag and hull structure	Cheaper and easier assembly	Poor anti-corrosion capability	Apply to ACV/SESs
4	Nylon bolts	Bag and bag and fingers	Light	Low strength, very expensive	Recreation craft
5	Piano hinge joints	Bag and hull structure	Easy to assemble	Complicated manufacture	Used widely in BHC
6	Cap-like joint (Bonio's)	Bag and bag and fingers	Fine joining strength, low self-damage possibility	Complicated manufacture	Used widely in China and BHC
7	Aluminium plates plus steel bolts (or nylon plates plus steel bolts)	Bag and bag	Fine joining strength, low self-damage possibility	Difficult assembly	Used in China for ACVs and SESs
8	Compression plates joint	Bag and hull	Easy to assemble	Unsatisfactory joining strength for ACV/SESs of medium size	Used in China for ACVs and SESs

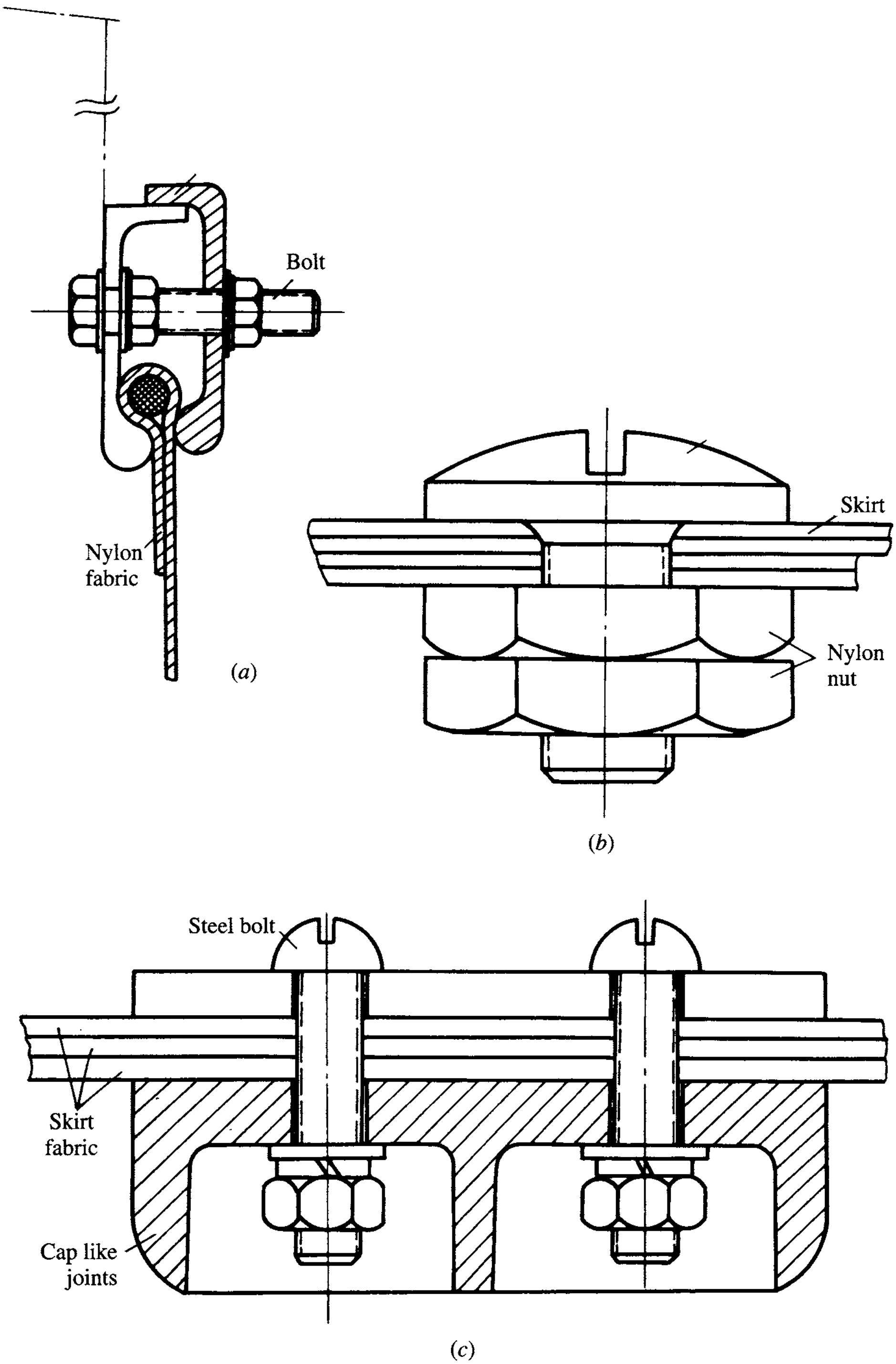

Fig. 13.12 Several types of skirt joints. (a) Clamped joint for bag/hull; (b) nylon bolt for bag and finger panel constructions; (c) steel bolts and plates for bag/finger panels.

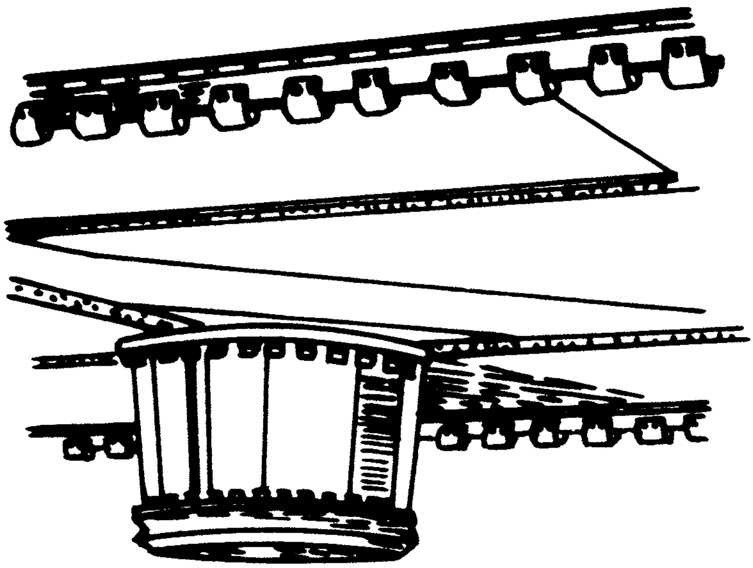

Fig. 13.13 Skirt attachments of piano hinge type on hull, which is normally used by BHC.

to the hovercraft. Items 2, 3 and 5–8 in Table 13.5 are widely used on Chinese hovercraft, item 6 among them is very similar to the 'Bonio's' of BHC, which are widely used on the BHC ACVs. The material of such joints is nylon 1010, but the material of Bonio's is rubber or neoprene, which is softer and more suitable to avoid self-damage of skirts.

13.8 Assembly and manufacturing technology for skirts

Assembly and manufacturing technology is dependent on attention to detail for success. Many skirt failures in the past have been due to the poor assembly and manufacturing technology of skirts. Skirt life may be demonstrated to improve by a factor of 10 just due to improvements in assembly or manufacturing technology of skirts, as has been experienced between the skirts of SES 717-II and SES 717-III. For this reason, we would like to introduce some examples, which are considered instructive to the designer.

Skirt tailoring and cutting of skirt air feed holes

It is suggested not to use scissors or a knife to cut skirt materials, because this will tend to part the the rubber coating from the fibres and encourage capillary suction of salt water into the fabric, which will become a key cause of rubber delamination. According to ref. 101, BHC earlier used a laser beam to cut the skirt. The disadvantage of this is a reduction in static strength of 15% of the fabric and a reduction of fatigue strength of 20% of the skirts. BHC therefore replaced this method with a water jet with a 0.15 mm diameter of jet of water at 345 kpa, which was sufficiently powerful to cut though skirt material, GRP and other laminates. They also used computer-aided manufacture as shown in Figs 13.14 and 13.15. In China, we use the

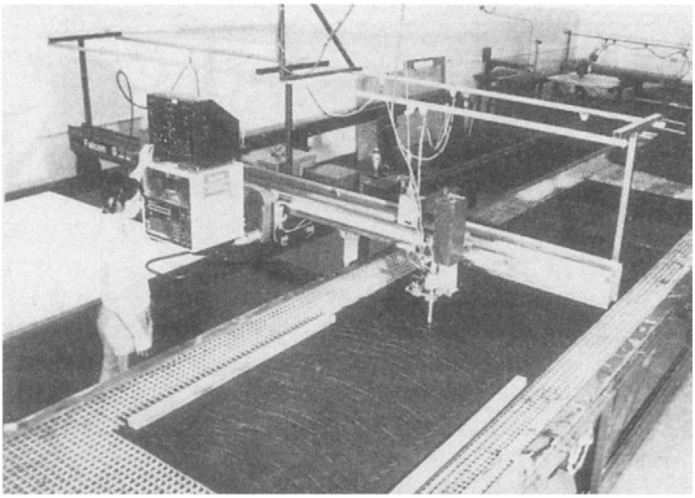

Fig. 13.14 The waterjet punching and cutting facility for skirt processing in BHC.

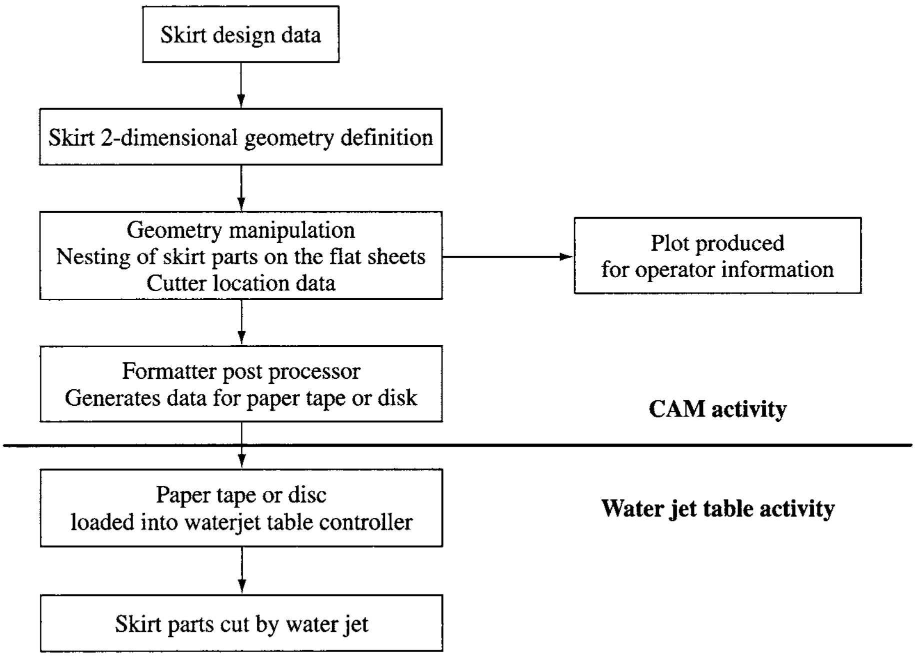

Fig. 13.15 The flow chart of CAM for the manufacture of skirts in BHC.

electric thermo-knife, which possesses the function of edge sealing. This has given good results for operational craft.

Avoid direct joining of skirt fingers with the bag

This is because the fabric might be ruined in the case of sideslip or reverse operation of craft, consequently large splits might be made in the bags.

Avoid building in assembly stresses

For example, owing to the poor manufacture of the bow skirt of SES version 719, large assembly stress existed, and as a result the overhaul life of the skirt was less than 20 hours! Assembly stresses can usually be seen from uneven geometry of the skirt.

Installation of diaphragms

With respect to bag diaphragms, there are two points of view. The skirt bag without a diaphragm has the advantage of uniform tension of the bag sheet and good formation of the skirt bag geometry. However, the skirt bag with a diaphragm will be restrained, with a concentrated stress exerting on the diaphragm, but it will improve resistance to skirt bounce and can also avoid interference between the water propellers and the stern skirts in the case of reverse motion of an SES on hull-borne operation.

13.9 Skirt configuration design

Skirt design begins by determining the various parameters and geometric relationships of the skirt sections at side bow and stern, such as X_A, X_c, a_E, Y_A Y_c Y_E, etc., as shown in Figs 13.16 and 13.17.

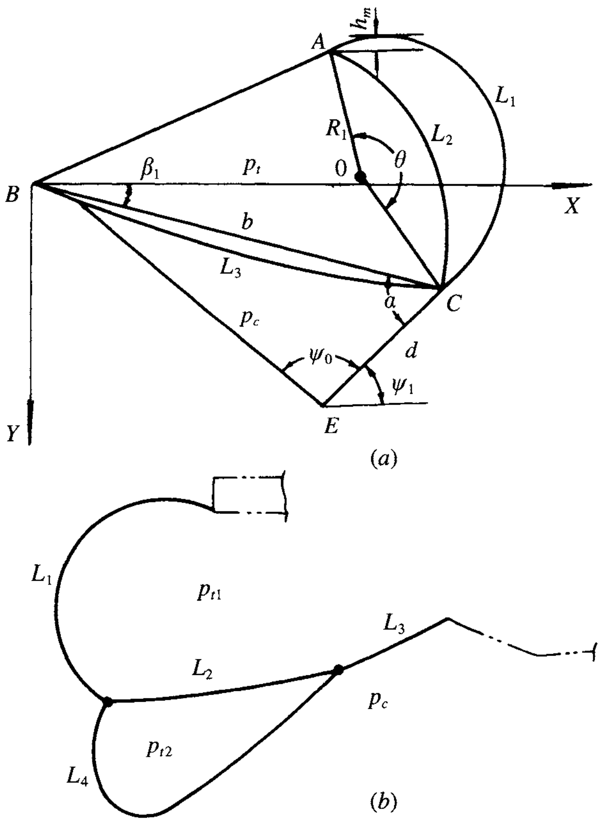

Fig. 13.16 Geometric features of skirts. (a) Skirt of bag and finger type; (b) Skirt of twin bag type.

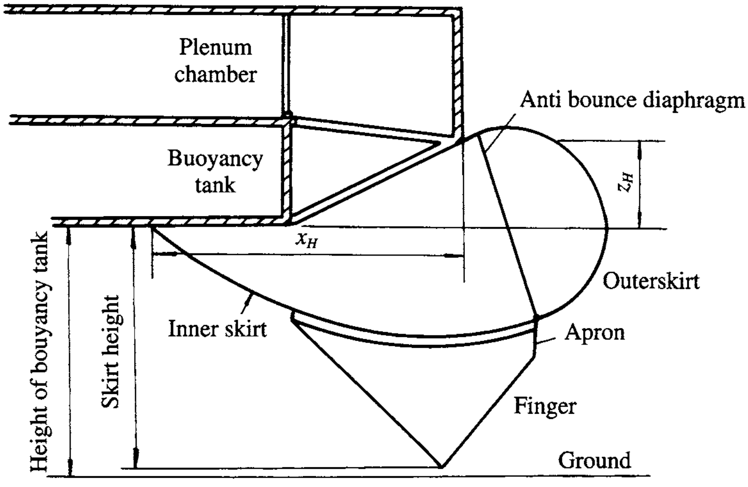

Fig. 13.17 Some geometric features of skirts.

Based on the requirements of craft performance, the size of the hull structure and the method for analysing the forces acting on skirts, designers can determine the skirt dimensions mentioned above, thus draw the static formation of the required skirt and begin the laying-off.

Skirt design is somewhat complicated due to the three-dimensional geometry of the membrane and the many parameters which have to be satisfied, including control or limitation of flutter, flagellation, bounce, etc. Skirts also affect craft performance parameters, such as tuck-under resistance, plough-in, speed performance, stability and seaworthiness. Skirt design should therefore be optimized in stages by using progressive refinement.

Statistical analysis method

Owing to the lack of comprehensive design methods for skirts in the 1970s some hovercraft manufacturers and designers, such as the British Hovercraft Corporation, Hovermarine International Limited, Hovercraft Development Limited and Vosper Thornycroft Limited, accompanied by some register units, as UK CAA, under the leadership of British Department of Industry, prepared the guidance document *Stability and Control of Hovercraft, Notes for Commanders* [48]. Table 13.6 defines the design factors affecting the leading side skirt tuck-under boundary, design factors affecting the craft's reserve against capsizing and the considerations on overall skirt geometry and craft parameters from this reference.

Design and analysis methods for skirts

So far there are no systematic and complete analytical design methods for skirts, so we introduce some design considerations on skirts and the determination of some skirt parameters for the reader's reference, as follows.

Determination of height of the bow/stern skirts

We can determine the height of the bow/stern skirts according to the requirements for seaworthiness. With respect to coastal hovercraft the slope of bow/stern skirt can be obtained from

$$\arctan \frac{(H_{skb} - H_{sks})}{L_c} \cong 0.4\text{–}0.55° \tag{13.2}$$

where H_{skb} and H_{sks} denote the height of bow and stern skirts respectively. This is not necessary for river hovercraft.

Bag and cushion pressure ratio (p_t/p_c)

This can be determined dependent upon the requirements for plough-in resistance

Table 13.6(a) Design factors affecting leading side skirt tuck under boundary [48]

Sectional geometry parameter	Comment	Current practice
$\frac{Z_h}{X_h} = \frac{\text{Hinge vertical spacing}}{\text{Hinge horizontal spacing}}$	High value favourable	0.15–1.0
$\frac{L_j}{X_h} = \frac{\text{Bag perimeter}}{\text{Hinge horizontal spacing}}$	High value favourable at lower pressure ratio of p_t/p_c	1.75–3.5
$\frac{B_c}{X_h} = \frac{\text{Cushion beam}}{\text{Hinge horizontal spacing}}$	Low value favourable	5.0–7.5
Finger depth per cent hull clearance	Low value favourable in theory, but some minimum value (>20%) probably optimum in practice due to better drag characteristics of finger than bag, even in purely beam-on condition	0.5–1.0
Overall skirt geometry and craft parameters		
Compartmentation	Centre keel with different pressure in roll favourable unless p_t/p_c for leading side skirt becomes low and Z_h/X_h and/or l_j/X_h are low	
$\frac{H_{sk}}{B_c} = \frac{\text{Skirt depth}}{\text{Cushion beam}}$	Low value favourable	0.10–0.2
$\frac{p_b}{p_c} = \frac{\text{Bag pressure}}{\text{Cushion pressure}}$	High value favourable	1.0–2.0
C_Δ = Cushion loading	High value favourable, usually	0.01–0.03
$\frac{H_{bt}}{H_{sk}} = \frac{\text{Buoyancy tank clearance}}{\text{Skirt depth}}$	High value favourable	0.80–1.1
$\frac{B_c}{le} = \frac{\text{Cushion beam}}{\text{Effective cushion length}}$	Low value favourable, in conjunction with H_{sk}/B_c and C_Δ, but only $(B_c/l_e)^{0.5}$ is as powerful as these	0.40–0.75

Table 13.6(b) Design factors affecting hovercraft's reserve against capsizing (up to tuck-under point)

Parameter	Comment	Current practice
Differential pressure rate less CG height moment parameter $\dfrac{\partial(\Delta p_c/p_c)}{\partial\theta}\;\dfrac{h_g}{B_c}$	A high value is favourable in this context, but will be offset by an adverse adjustment to the tuck-under merits if hinge spacing and bag perimeter ratios are not good (unless initial pressure ratio is high)	−0.3–0.6
$\dfrac{H_{bt}}{H_{sk}} = \dfrac{\text{Buoyancy tank clearance}}{\text{Skirt depth}}$	The importance of this parameter is modified by the size of the drag moment parameter, but a high value is favourable.	0.8–1.1
$\dfrac{H_g}{B_c\,C_\Delta} = \dfrac{\text{CG height ratio}}{\text{Cushion loading}}$	Drag moment parameter, low value favourable	10–25
$\dfrac{L_j}{X_h} = \dfrac{\text{Bag perimeter}}{\text{Horizontal hinge spacing}}$	Affected by beam increase. High value favourable	1.75–3.5
$\dfrac{p_t}{p_c} = \dfrac{\text{Bag pressure}}{\text{Cushion pressure}}$	Affects bag pressure moment, high value favourable	1.0–2.0
$\dfrac{B_c}{X_h} = \dfrac{\text{Cushion beam}}{\text{Horizontal hinge spacing}}$	Relates skirt contact moment to cushion beam dependent and other moments. Low value favourable	5.0–7.0

capability, seaworthiness and minimum lift power etc. In the past it might be taken as $p_t/p_c = 1.2$–1.5 for ACVs. So far, thanks to improvement in skirt design, the plough-in resistance of craft is greatly improved. For this reason, in order to save lift power, it can be taken as 1.0–1.3 for ACVs and 1.0–1.15 for SESs.

Finger height ratio h_f/h_{sk}

Here, h_f denotes the finger height and h_{sk} the overall height of the skirt, i.e. the vertical height of the bottom plates over the ground. Higher finger height gives better seaworthiness and obstacle clearance but worse stability. In general we take h_f/h_{sk} at around 0.5–0.8 This is a realistic value where pressurized bag skirt designs are used. Where an open loop design is used h_f/h_{sk} is normally between 0.85 and 0.95.

Inclination angle of fingers ψ_1 (Fig. 13.16)

According to the theory developed in Chapters 4 and 7 the smaller this angle, the better the static stability of craft accompanied with small drag, but if this angle is too small it will cause the decrease of cushion area to be too rapid for acceptable stability. In general we take ψ_1 to be between 40 and 50°.

Inward inclination angle ψ_0 (Fig. 13.16)

Too small ψ_0 will cause the wrinkling of skirt fingers at their front edge under the action of cushion pressure, but too large will use too much skirt material and weight; in general $\psi_0 \geqslant 90°$.

Determination of deformability or stiffness of skirts

The main parameters for study of skirt deformability are as follows:

1. the static deformability in vertical and horizontal direction

$$\Delta X_E / \Delta p_c \qquad \Delta Y_E / \Delta p_c \quad (\text{mm/(N/m}^2))$$

2. the inherent frequency and damping coefficients.

So far, there are no clear analytical theories of how skirt deformability improves hovercraft performance, however it is mainly dependent on the operational environment for a particular craft. For this reason, according to the requirements for the seaworthiness of craft, designers generally select two or three different deformabilities of skirts and study the performance of craft with such skirt deformability with the aid of experimental tank results or computer analysis.

Designers can then judge from the test results and select the optimum deformability of the designed skirt. The inherent frequency of a responsive skirt (one with lower stiffness of the bag geometry) should be lower than the wave encounter frequency of the component wave on which the peak wave energy of the irregular wave spectrum occurs.

With respect to small ACVs operating on rivers, it is suggested not to use the responsive skirt with low natural frequency, because the anti-plough-in capability of this design is degraded and may cause plough-in. Similar to the ACV, the SES so far also adopts stiffer skirt geometries with small deformability.

As far as the coastal ACV, or ACV with good seaworthiness are concerned, it is suggested to adopt the responsive skirt, but the deformability of the bow skirt should be smaller than that of the side skirt in order to prevent tuck-under of the bow skirt during operation of the craft in a following wind. The deformability of the stern skirt should be larger than that of the side skirt in order to improve the take-off performance and seaworthiness of craft in waves.

During preliminary and project design, the calculation mentioned above generally cannot be carried out because of lack of required data. The following two geometric parameters, which greatly affect the deformability of skirts, are offered for judging the responsiveness of the designed skirt at this stage, i.e., if

$$\frac{X_E}{X_A} > 1.0$$

then the skirt obviously becomes a responsive skirt (the larger this value the more deformable the skirt), and if

$$\frac{h_m}{R} > 0$$

then this skirt will also be a responsive skirt. The larger this value, the more deformable the skirt, therefore the responsive skirt is also often called a skirt with protruding shoulder.

The parameters mentioned above are very important and become the main criteria characterizing the responsiveness of skirts. When adopting the responsive skirt the designers have to check the tuck-under capability of the skirts, namely to estimate if tuck-under might occur to the skirt while the craft has negative trim angle and significant immersed depth of the bow skirt (H_w), at any given craft speed.

In order to improve the tuck-under resistance and anti-bounce capability, in general the D-type skirt bag (with inner membrane) will be fitted on bow skirts and longitudinal anti-bounce diaphragms on the side skirt. These membranes are needed where bag pressures above $1.3p_c$ are used.

Special attention has to be paid to the design of ACV/SES corner skirts, since the skirts there are in three dimensions and have to be designed and calculated according to the three dimensional principle of skirt formation, otherwise the air gap under the skirts in this area will be non-uniform and cause a large amount of air leakage and spray.

With respect to the SES, in general, the 'rigid' (i.e. with less responsiveness) bag–finger skirt, or simple deep segments, may be mounted at the bow in order to obtain anti-tuck-under and anti-plough-in capabilities, leaving control of pitch motion to the sidewall lines and perhaps damping mechanisms such as bow foils.

As far as the stern skirt is concerned, the twin bag or triple bag with large responsiveness (i.e. low p_1/p_c ratio) may be mounted on both ACV/SES as discussed in Chapter 7. Owing to lack of a suitable method to predict the formation of the stern skirt, determination and checking of the geometry of the skirts is normally by means of model experiments, in a skirt box and subsequently in a towing tank.

After determination of the responsiveness, the various geometric dimensions may thus be designed. This is followed by possible additional skirt components as outlined below.

Longitudinal and transverse stability trunks

The height and type of arrangement in plan (+ type or T type) of longitudinal and transverse stability trunks can be obtained according to the methods in Chapter 4. Positive trim angles of craft have to be considered in order to avoid excessive wear of longitudinal trunks at the stern during landing of craft. It is also normal to make a 20–30° back inclination angle on transverse stability trunks during installation of the skirt in order to reduce the craft drag in waves.

Spray suppression skirts

In order to suppress spray, a spray apron or skirt can be mounted at the bow and side skirts of amphibious ACVs. Experience shows that this skirt is especially effective when mounted on low-speed air cushion platforms.

There are two main types of spray skirt normally used, the external inflated tooth and the 'apron'. The US Navy LCAC craft are fitted with the spray suppression teeth (see Fig. 7.38(b)) to depress spray when manœuvring at slow speed around a landing ship, or close to shore. They are similar to a double segment and may be inflated either from the loop, or from the outer face of the segment to which they are attached at its outer hem.

An apron skirt is more commonly used by utility craft. Many AP.1-88 craft have these fitted, (see Fig. 7.38(a)). A shaped apron of medium-weight skirt material simply lies over the outer part of the bow and side bag/loop skirts. Tethers attach it to the upper loop hem line. At its outside the apron hangs vertically to a level about mid-height of the finger or segment, when the craft is at full hover height. This skirt will tend to flap somewhat, which does not improve the attractiveness of the ACV's looks, but especially for operations over ice and snow this helps to maintain the skirt clear of ice. If the apron is too long, it can affect craft dynamic behaviour and speed loss in waves. If this should prove to be the case when a craft is put on trials, a careful programme of trimming will allow optimization of the spray suppression and minimize effect on performance in a seaway.

A recent modification of the AP.1-88 'maxi-apron' is to attach a smaller apron to the segment or finger upper attachment point. This short apron hangs approximately half the segment height. Some holes should be punched in the upper part of the apron to reduce the pressure build-up.