10

Design methodology and performance estimation

10.1 Design methodology

In the next seven chapters we will introduce design methodology for ACV and SES craft. This includes selection of equipment for the major craft subsystems, which forms an essential part of the design process.

In principle, ACV and SES design does not differ substantially from that of conventional ships. Some hovercraft subsystems are also very similar to those in conventional ships, particularly on SES. In the following chapters, we will concentrate on the design features of ACV and SES which differ from the norm. Readers are referred to [21], [129] and [207] as starting points for reference data on craft which have been constructed.

It is assumed that readers will have an appreciation of the general design philosophy and methods for some conventional ship subsystems, such as propeller design, power plant specification, hull structural design, design of ship's outfit and systems, etc. The content of the following chapters will thus be limited to the special needs of ACVs, with appropriate reference to suitable standard naval architecture texts for the remainder, to simplify the treatment here. A number of specialist texts are also listed in the references section following Chapter 16.

In the course of describing the design method for ACV/SES, the subjects which have been introduced in Chapters 2–9 form the basic input, such as air cushion performance, drag, stability and manœuvrability, the force analysis for skirts and the calculation of skirt geometry, etc. which form the basic theories of ACV/SES.

ACV and SES initial design requires three sets of requirements to be input:

- user requirements, such as craft speed, payload, range, economy, weather limitations;
- statutory requirements to be satisfied by the craft, such as stability and safety criteria;
- the main features of ACV/SES which control their principal dimensions, including the lift power, propulsion power and type of propulsors, as well as the main structural style of the hull and skirt, etc.; these are selected by the designer as he/she proceeds.

The various performance parameters and required installed power of a craft can be predicted using the analytical and model test methods presented in Chapters 2–9, once the principal dimensions and some key requirements for performance of craft have been chosen. For this reason, the initial design process of ACV/SES may be grouped in sections as follows.

Stage 1: Establish key design parameters

Specification of criteria and standards for use during the design of ACV/SES are provided as general guidance by national authorities such as the IMO [215], the UK Civil Aviation Authority [200], Canadian Coastguard, US Coastguard, Classification Societies [223], etc. The following criteria are normally specified:

- intact stability criteria;
- damaged stability and buoyancy compartmentation requirements;
- requirements for seaworthiness;
- weather limitation capability;
- requirements for manœuvrability;
- requirements for habitability, such as internal/external noise and vibration level, etc.
- requirements for machinery and control system redundancy.

The initial craft design is checked against these requirements and adjusted as required, prior to completion of the detail design of the craft for construction purposes.

Stage 2: Determination of principal dimensions

- payload specification;
- craft overall dimensions;
- craft weight estimate and distribution;
- parametric studies (as required for optimization purposes).

At this stage general relationships for required power (SHP/tonne knot), craft sizing, etc. are used, based on past experience. The necessary data for this are presented in Chapter 11.

Stage 3: Principal subsystem design

- skirt and cushion system
- lift system
- propulsion system
- selection of main equipment
- initial design of hull structure, etc.

The initial subsystem data will be revised based on data generated for the craft being designed. The methods described in Chapters 2–9 are used to prepare the system analyses.

In this chapter, we will introduce typical criteria and standards for the various design parameters, which allow the designer to continue with determination of principal dimensions in Chapter 11. Some of the design criteria for hovercraft have been discussed in Chapters 2–9, such as relative transverse metacentric height (h/B_c), to characterize the transverse stability of an SES, and the shifting distance of the centre of cushion pressure to characterize the transverse/longitudinal stability of ACVs etc.

There is no single consistent set of standards for ACV and SES design, therefore we take the following documents as the main references during design of hovercraft:

1. some design rules and regulations such as the UK CAA BHSRs and IMO rules [200], [215];
2. safety requirements for dynamically supported marine vehicles [106], [94];
3. some provisional safety requirements and rules published by some countries as [202], [97], [95], etc.

The following discussions mainly concern hovercraft in cushion-borne operation. The craft also have to satisfy the requirements from the rules and regulations for hull-borne operation, which we will not detail because this is similar to the design of conventional ships.

10.2 Stability requirements and standards

In the various rules and regulations available at present, requirements are often not specific to dynamically supported and high-speed craft, the category which includes hovercraft. A large amount of information from model experiments and craft trials is already available which allows us to propose criteria for the safe operation of hovercraft. We outline these below, followed by some discussion of the principal rules available internationally at present, the IMO requirements and the UK BHSRs .

Principal dimensions and parameters

ACV – stability and cushion height

Reference 52 considered that if the air cushion can be compartmented reasonably and a flexible skirt with bag cushion pressure ratio $p_t/p_c = 1.3$ can be adopted, then the skirt height should meet the following expressions:

$$h_{sk}/B_c \leq 0.17 \tag{10.1}$$

$$(z_g + h_{sk})/B_c \leq 0.33 \tag{10.2}$$

where h_{sk} is the height of flexible skirt (m), z_{cg} the vertical height of the CG (m) and B_c the cushion beam (m). In addition, based on statistical data from existing craft, allowable skirt height can be determined as in Fig. 10.1.

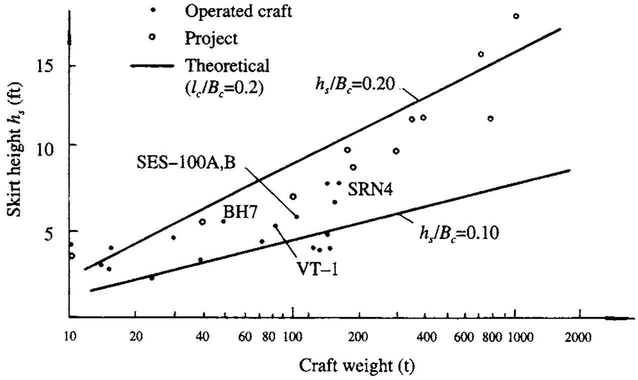

Fig. 10.1 ACV/SES skirt height statistics.

SES – stability and cushion height

The transverse stability of an SES on cushion is closely related to the cushion length/beam ratio, as described in Chapter 5. Based on statistics from previous craft, this should comply with Fig. 10.2. These relationships can be used at the concept design stage, in which the craft principal dimensions have not yet been determined. Figure 10.2 shows that the sidewall thickness ratio of Chinese SES with high L_c/B_c is rather small, but practice proved that these craft, such as the 717-II and -III, have good transverse stability while they are operating in the upper stream of the Yangtze River. For this reason, it is found that the sidewall thickness ratio (B_{sw}/B_c) is not the only criterion to characterize the transverse stability of the SES, but can still be used as a reference for designers during preliminary design.

Transverse and longitudinal metacentric heights

These are very important criteria to characterize the stability of craft, particularly in the case of craft with large cushion beam and at small heeling angles; therefore, in general, designers always take this as the parameter for characterizing the transverse and longitudinal stability. According to [52], they can be written as follows. For ACVs

$$\bar{h}_\theta = h_\theta/B_c \geqslant 0.3\text{–}0.4$$
$$\bar{h}_\psi = h_\psi/l_c \geqslant 1.0\text{–}1.5 \tag{10.3}$$

For British ACVs, ref. 19 recommended

$$h_{\theta g}/B_c = 0.6\text{–}1.2$$
$$h_{\psi g}/l_c = 1.2\text{–}2.4$$

where $h_{\theta g}$, $h_{\psi g}$ denote the dimensionless transverse and longitudinal metacentric heights of an ACV hovering on a rigid supporting surface.

For SESs, typically the Hovermarine HM-2 for example,

$$h_\theta/B_c = 0.36$$
$$h_\psi/l_c = 0.69$$

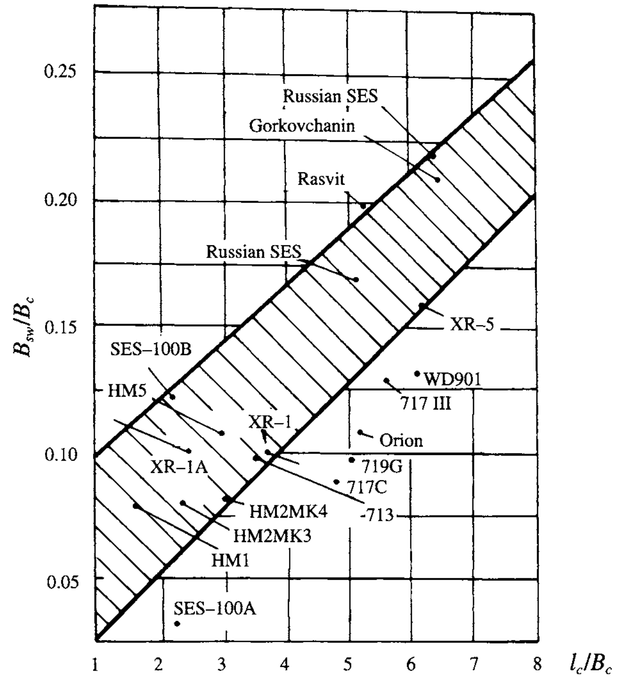

Fig. 10.2 Relative sidewall thickness B_{sw}/B_c and cushion length/beam ratio of SES on cushion. [4]

In Chinese practice during development of ACV/SES, it has been found that the values of these criteria are quite flexible. At the early stage of SES development (1966–79), owing to lack of a calculation method for predicting stability, the SES stability criteria used were wholly dependent upon the relative sidewall thickness (B_{sw}/B_c) as shown in Fig. 10.2. This criterion for characterizing the stability does not uniquely characterize the craft stability, because it does not consider the sidewall draft, the ratio of sidewall displacement and all-up weight, air flow rate and sidewall geometric configuration. For example, the Chinese SES-719G has $l_c/B_c = 5.05$, $B_{sw}/B_c = 0.088$, while SES-717C has $l_c/B_c = 4.94$ and $B_{sw}/B_c = 0.077$, but the transverse stability of the former is far better than the latter, which was proven in the craft trials.

In the early stage of design and manufacture of hovercraft in China, particularly SES, due to the use of thin sidewalls for reducing drag and pursuing high speed, the craft's transverse stability was not satisfactory for open water operation. However they could be operated safely in inland rivers, upstream of the Yangtze River for example, but not the more demanding environment such as in the estuary of the same river.

MARIC has much experience of the effect of various factors on the transverse stability and the operational performance of SES with poor transverse stability. In the beginning of the 1980s, they developed a calculation method for predicting the transverse stability (see Chapter 4, section 2) and subsequently developed comparative evaluation methods to build on this experience.

The relative transverse metacentric heights for Chinese SES are listed in Table 10.1. It can be seen from this table that for SES operating in inland rivers h_θ/B_c should be

Table 10.1 Relative transverse metacentric height for several Chinese SES

	Type of craft				
	717C	711-III	719G	717-III	713
Year constructed	1980	1966	1982	1981	1969
Cushion length/beam ratio l_c/B_c	4.94	3.5	5.05	5.7	3.5
Transverse metacentric height h_θ/B_c	0.17	0.08	0.306	0.398	0.38
Relative sidewall thickness B_{sw}/B_c	0.077	0.062	0.088	0.13	0.086
Calculation method for transverse metacentric height	Computer. Close to experimental results	Computer analysis	Computer analysis	Computer analysis	Experience method *
Operating experience during trials	Poor	Very poor	Good	Fine	Good

*Offered by Andrew Blyth of UK.

greater than 0.25–0.30 and for SESs running in river estuaries (more exposed conditions), it is suggested that h_θ/B_c should be greater than 0.40.

David R. Lavis [57, 92] also presented some statistical material demonstrating the stability of ACV/SES and the capsizing of various ships as shown in Fig. 10.3, in which the hatched zone denotes the capsized conventional displacement ship and hovercraft. It can be seen that the Chinese experimental craft 711-III and 717C are also included in this area. It is possible this is realistic; if these craft are operated at a rivermouth or coast then they would be insufficiently stable.

From Fig. 10.3, it is seen that the suggestion offered by the CAA in the UK, [93] namely all craft have to meet the requirements of $h_\theta/B_c > 0.4$–0.5, is close to MARIC's experience.

The ratio of skirt height with the cushion beam is not the sole criterion to characterize the stability for ACVs, and designers also have to consider the configuration of both peripheral skirts and stability skirts.

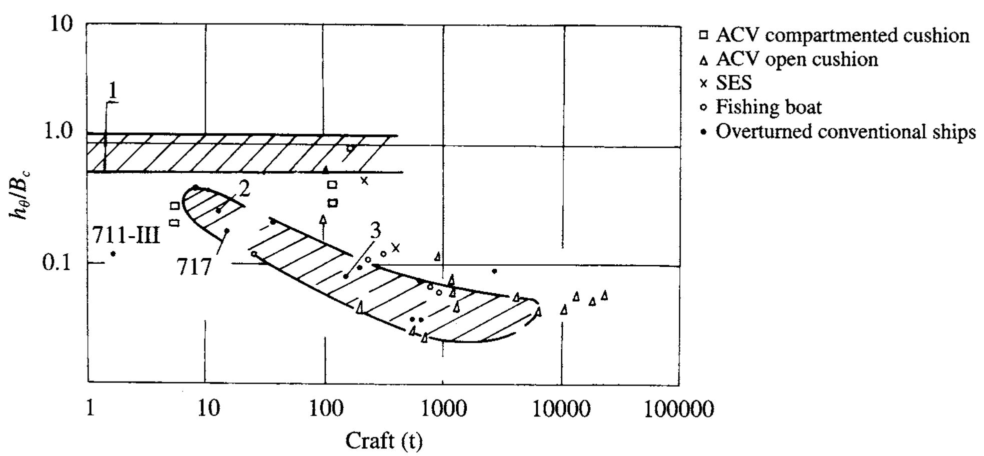

Fig. 10.3 Comparison of initial static transverse stability between conventional ships and ACV/SES: (1) stability range for ACV/SES suggested by CAA; (2) range for overturned ACV/SES (hatched area); (3) range for overturned conventional ships (hatched area).

In the early stage of hovercraft development the main criterion for stability was the craft's skirt height. It was considered that the craft would be safe if $h_{sk} < 0.2B_c$, where h_{sk} denotes skirt height. The designer generally determined skirt height according to statistical references, for instance, the skirt height can be determined by Fig. 10.1 according to the craft weight. From Fig. 10.1, it is seen that the data, which include craft both from China and elsewhere, are closely concentrated. Fig. 10.4 shows the relation between height of craft CG and skirt height. The data points are very concentrated here also. It seems from this that general arrangements for the various ACVs are similar.

Figure 10.5 shows the relation between rolling stiffness of hovercraft with the cushion depth–beam ratio, in which S_R denotes the rolling stiffness, i.e. the relative shifting distance at cushion centre of pressure per degree of heeling angle, which is also related to the relative transverse metacentric height. This is because we have $h_\theta/B_c = S_R \times 57.29$ (shown in Chapter 4).

In Fig. 10.5, curve 1 shows the stability requirements of the UK Civil Aviation Administration (CAA). Curve 2 shows the envelope for relative skirt height, below which no overturning of craft has occurred to date. It can be seen that the CAA requires the ratio of skirt height to cushion beam to be smaller than 0.2. For 'ordinary' skirts, we consider that this requirement is reasonable and practical, but if a responsive skirt with large deformability is adopted, the requirements have to be seriously reconsidered, because responsive skirts generally have lower transverse stability. It is suggested that it is better to judge the stability by relative metacentric height in this case.

Calculation of initial stability for both ACV/SES is obtained by the methods presented in Chapter 4. The stability for a number of craft which have been built are as listed in Table 10.2. Based on this table the following requirements for an ACV may be considered reasonable:

$$h_{sk}/B_c < 0.2 \tag{10.4}$$

$$h_\theta/B_c > 0.35\text{–}0.4 \tag{10.5}$$

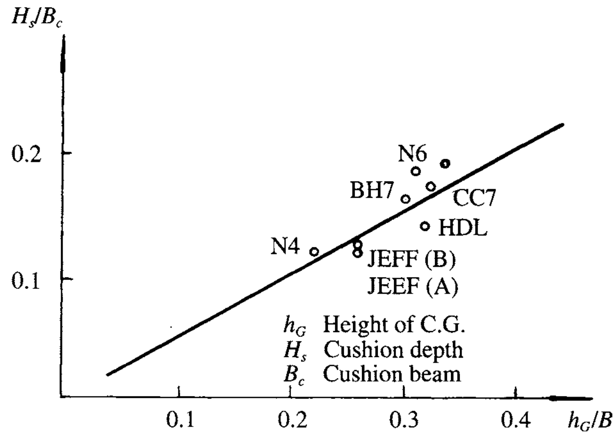

Fig. 10.4 Vertical CG position compared to ACV cushion heights.

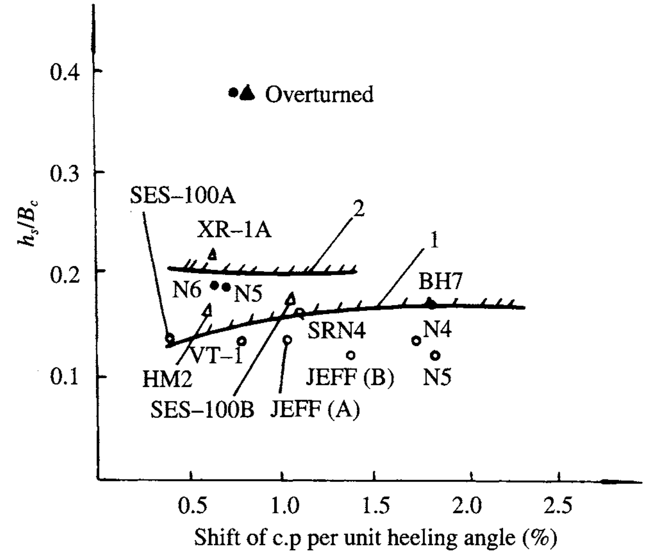

Fig. 10.5 Transverse roll stiffness versus cushion height/width ratio H_s/B_c: (1) stability requirements for ACV/SES proposed by UK CAA; (2) the boundary line for transverse roll stiffness with respect to relative skirt height.

Meanwhile initial stability has to comply with the following conditions:

1. *The requirements for extreme transverse rolling angle.* The transverse stability of a craft has to be checked for all relevant intact and damaged operational conditions on waterways within a distance of 100 nautical miles from the home port. The safety requirement for dynamically supported craft [215] issued by the Intergovernmental Maritime Consultative Organization (IMO) proposes the following:

   The stability of ACVand SES should be such that the heeling angle should not be larger than 8° with respect to the sea level at any direction of craft at the maximum permitted load running on calm water and wind condition. The initial stability of a craft should be determined in the worst operational environment.

2. During craft turning at high speed, the heeling angle should not exceed 8°.

Table 10.2 Static transverse initial stability of various ACVs

	Craft								
	HD.2	VT.2	CC.7	SR.N6 Mk 1	SR.N4 Mk 2	SR.N4 Mk 3	BH.7	7202	711-III
Country	UK	UK	UK	UK	UK	UK	UK	China	China
h_0/B_c	0.206	0.286	0.326	0.716	0.475	0.510	0.596	0.470	0.578
h_ψ/l_c	0.791	0.573	0.393	2.290	1.140	1.776	1.530	??	0.750
Stability measures	b	b	b	a	a	a	a	a	a

a = Cushion compartmented and skirt lifting system.
b = Cushion not compartmented, horizontal skirt shift system installed.

Requirements for stability at large heeling angles

During estimation of the effect of beam wind on ACV/SES stability designers have to consider the combined action of both wind and waves on craft. In general the wind force is considered as the controlling force. The heeling moment arm due to the wind force can be written as

$$l_m = KV_w S_B (l_w - 0.5T) / (W_v \cos^2\theta) \tag{10.6}$$

where l_m is the arm of heeling moment due to the wind force (m), l_w the arm from base plane to centre of area of wind pressure (m), v_w the wind speed (m/s), S_B the area under the action of wind force (m^2), θ the heeling angle (°), T the draft (m), K the coefficient, it is normal to use $K = 0.726 \times 10^{-4}$, and W_v the volume displacement (m^3).

The SES, due to its large craft beam and the presence of sidewall buoyancy at a large moment arm, is impossible to roll to large angles, therefore 15° rolling angle can be considered as the extreme heeling angle for calculation in the upwind direction, compared to 25° normally used for conventional single-hull ships.

The transverse stability of an ACV under the action of heeling moment due to the wind pressure can be calculated by plotting the data as in Fig. 10.6, which shows the stability curve and heeling moment curve of ACVs SR.N4 and SR.N6, which should satisfy the following conditions:

1. During heeling, the balance angle θ_0 between heeling moment and static stability righting moment does not exceed 60% of the maximum restoring moment arm.
2. $S_1 \geqslant 1.4S_2$.

Reference 52 gave these requirements for craft stability during hull-borne operation, which also defined the requirements for transverse stability of hull-borne craft during loading and lifting cargo. However, hovercraft which capsize are often in

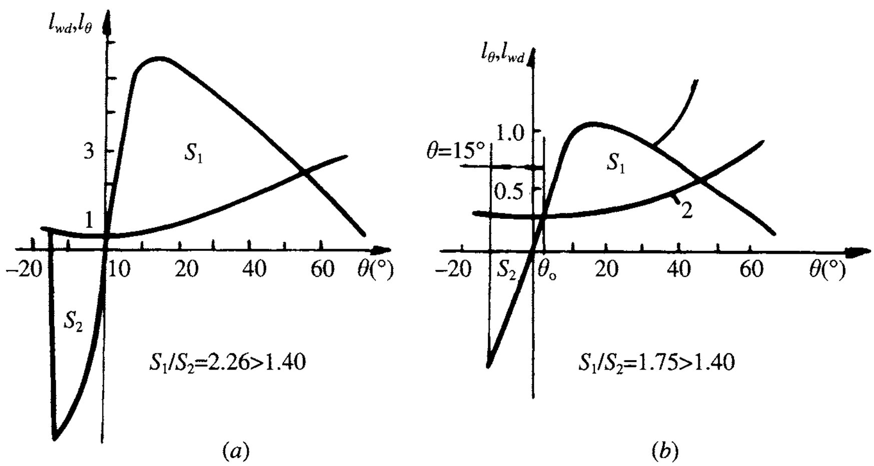

Fig. 10.6 Static stability curves of SR.N6 and SR.N4 in winds, with speed of 28.3 and 33.5 m/s respectively: (a) SR.N4 (weighing 182t); (b) SR.N6 (weighing 9.1t). 1: static stability; 2: heeling moment.

cushion-borne operation as shown in Fig. 5.54, particularly under the action of combined winds and waves, for the following reasons:

1. The transverse stability is lower in cushion-borne operation compared with floating mode.
2. Moment due to the centrifugal force of craft will be increased at high speed.

Research is ongoing on the effect of combined wind and waves action on hovercraft on cushion. This research is not complete; however, the calculation method predicting the roll angle of an SES on cushion in waves can be carried out according to the methods in Chapter 8.

During the investigation of stability, craft with icing on the surface of the craft superstructure may have to be checked. According to the IMO it is suggested that on offshore hovercraft the thickness of the icing layer may be 30 kg/m^2 on all unsheltered surfaces, such as the deck and the top of navigation cabin, etc. and 7.5 kg/m^2 on all perpendicular sides of superstructures. In order to estimate the icing on ropes, handrails and other deck-mounted items it is suggested that the thickness of icing on such surfaces will be the perpendicular icing layer plus 5%, and an increase 10% in moment, caused by such weights.

These standards may be decreased to half in the case where the ACV/SES operates in navigation regions where icing seldom occurs. Owing to the large width of hovercraft, the extreme rolling angle, which is closely related to the relative cushion height (cushion depth/cushion beam) is small, about 15° as shown in Fig. 10.7, because the transverse stability increases rapidly once the wet deck (lowest hull surface) is immersed in the water.

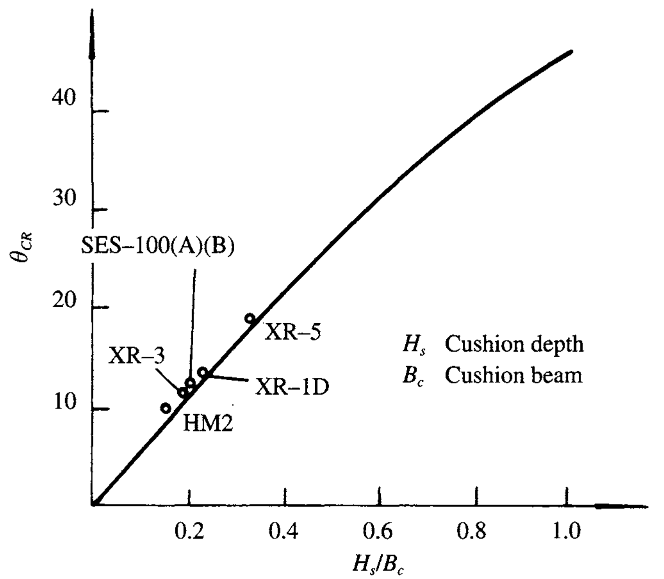

Fig. 10.7 Limiting roll angles of ACV/SES versus relative cushion height.

10.3 Requirements for damaged stability

Calculation of damaged length, width and depth

According to the IMO, hovercraft have to have positive stability and buoyancy from the water surface in the case where the bottom and/or side of craft are damaged. In addition, the heel or trim angles are not to exceed 8° and the final craft freeboard, over any holes which may enter the water shall be at least 75 mm [215, 93]. Based on these requirements, the following data can be used in calculations:

Side damage:	
Longitudinal direction:	$0.1L$ or $[0.03L + 3 \text{ m}]$ or 11 m
Depth direction:	No less than $0.2 \times$ width of buoyancy tank for an ACV or $0.2B$ (or 5 m) for an SES,
Vertical direction:	Whole depth of sidewalls
Bottom damage:	
Longitudinal direction:	$0.1L$ or $[0.03L + 3 \text{ m}]$ or 11 m
Transverse direction:	$0.2B$, where B is craft width, or 5 m, or less than the space between the sidewalls
Depth direction:	$0.02B$ (or 0.5 m)

The buoyancy of an ACV is provided by the buoyancy tank. When calculating buoyancy, it is suggested that the superstructure is not included as part of the watertight region.

Calculation of damaged stability

Damaged stability and floodability can be obtained with the aid of classification regulations and construction rules of the inland river ship rules of the USSR [86]. The following checks are proposed to be carried out:

1. Based on damaged conditions from 10.3, calculate the floodability of craft in the case of damage.
2. During calculation of craft floodability, the free volume coefficient should be considered as 0.95 in passenger and crew cabins, 0.80 in machinery areas and 0.6 in cargo holds.
3. According to this calculation, the craft have to float and the distances between the waterline and upper deck (or holes) are no less than 75 mm.
4. The transverse metacentric height of a damaged craft should be no less than 0.05 m and the area under the envelope of the transverse stability curve should be positive. The maximum transverse stability arm should be no less than 0.01 m, the range of positive transverse stability should be larger than 30° in the case of symetric immersion and no less than 20° in the case of asymmetric immersion.

10.4 Requirements for seaworthiness

In general, users base the requirements on the weather restrictions limiting hovercraft operations. Thus a route or mission requirement may demand a craft to operate in a certain sea state and wind force.

Stability of craft in waves

The stability requirements of craft under the action of a given combination of wind and waves can be obtained with the aid of calculation methods presented in Chapters 4 and 5, model test results and statistics from existing craft. While there are some simple guidelines which control craft design due to waves (planing surface angles for ACV buoyancy tank side and bow to be greater than 5° when the skirt at one side or bow has collapsed, for example), the majority of requirements are linked to craft performance or passenger comfort.

Speed degradation and craft's ability to accelerate though hump

The speed degradation and hump transition speed of craft in wind and waves are very important, particularly for an ACV. The expression 'craft can be operated in a certain scale of wind and waves' implies that the craft can be operated at an acceptable post-hump speed on cushion in the defined wind and waves, even though the speed may be far less than that on calm water. The speed loss and the ability for cushion-borne operation can be calculated according to Chapter 8 or model experiments to check if the design can satisfy the requirements desired by the users. This will generally determine the required reserve power of the craft.

Slamming forces in waves

Slamming is normally designed by interpolation from special model tests, or from data presented in references such as the BHSRs [79], Chapter B4–2. The slamming pressures of ACV hulls are typically 50% less than that of conventional planing hull, while those at the bow of SES sidehulls are similar.

Du Cane [87] suggests that for planing boats a typical design peak pressure may be about 3.45 bar acting over a small area of 0.1–0.2 m^2, based on measurements from fast patrol craft. Such pressures occur in the forward 30% of a craft's length. Structural members supporting a significant area of the bottom panels, i.e. deep longitudinal or transverse frames, should be designed on the basis of 2.07 bar pressure. Pressures are assumed to fall away linearly to 25% at the stern.

The BHSRs give a rather more detailed analysis procedure based on the following equation:

$$p = 0.0324\, K_2\, V_v\, V$$

where p is the pressure (lb/in^2), K_2 the empirical hull station weighting factor (2.0 at bow, 1.0 at 22.5% craft length from bow), V the craft overwater speed (ft/s), V_v the relative vertical velocity (ft/s) and is

$$V_v = 2.26\,\pi H/(l_w^{0.5}) + V_s$$

where H is the wave height (ft), l_w the wavelength (ft) and V_s the rate of sink (ft/s) (use 2.0 ft/s unless better data are available).

The vertical acceleration is often considered to be the limiting condition for the crews and passengers; however, most damage to mountings, pipe systems, equipment and passenger chairs arises from slamming accelerations and mechanical vibration. Therefore the design requirements have to be chosen carefully; check the slamming acceleration and use this as the limiting condition if appropriate. Vibration dampers are selected according to the requirements discussed in Chapter 14.

During preliminary design, limitations to be considered by designers may be similar to those offered by ref. 52 for ACVs:

1. A well-designed ACV may travel safely on cushion in the waves with maximum wave height of $(1.3–1.5)h_{sk}$, where h_{sk} denotes the height of the flexible skirt. The significant, or 'visible' wavelength will be in the range 0.80-1.0 h_{sk}. However, the speed loss will be high, up to 50% of calm water maximum speed, dependent on wind direction.
2. In the case where maximum wave height is approximately equal to $0.8h_{sk}$ the ACV should be able to travel normally at any course with respect to the direction of the waves, but with a speed loss of about 25%.
3. Due to the $h_{sk}/B_c \leqslant 0.17$ for meeting the stability requirements, so ACVs are able to operate normally on cushion in waves with height of less than $(0.22–0.25)B_c$, i.e. at normal angles of yaw and rates of sideslip

10.5 Requirements for habitability

Habitability criteria directly influence the comfort of crew and passengers and operability of instruments and equipment. Motion amplitude and accelerations control the design of equipment. For example, seat mountings, engine mountings, etc. need to be designed to accept loadings of up to 4*g* [79, 88] due to accelerations and slamming loads, while resilient mountings for instruments need to provide damping for vibration from wave period and cushion natural period oscillations.

Due to the high craft speed and lightweight hull structure, high power plant output and high speed of various rotating machines, such as lift fan, propellers, gear boxes, hydraulic pumps and motors, hovercraft have in the past been characterized by significant on-board vibration, high noise level and large vertical accelerations. Such factors reduce the craft's habitability, which mean the crews and passengers find it difficult to travel, work and live on the craft. Meanwhile, they also influence the operational condition of equipment and apparatus of the craft. Here we will discuss mainly the effect of vertical acceleration and internal as well are external noise levels on the habitability of craft for personnel.

Vertical acceleration

Passenger craft have to satisfy the requirements stipulated by the IMO and the International Standards Organization (ISO), which are based on a large amount of test and statistical information. Figure 10.8 shows thc vertical acceleration data for

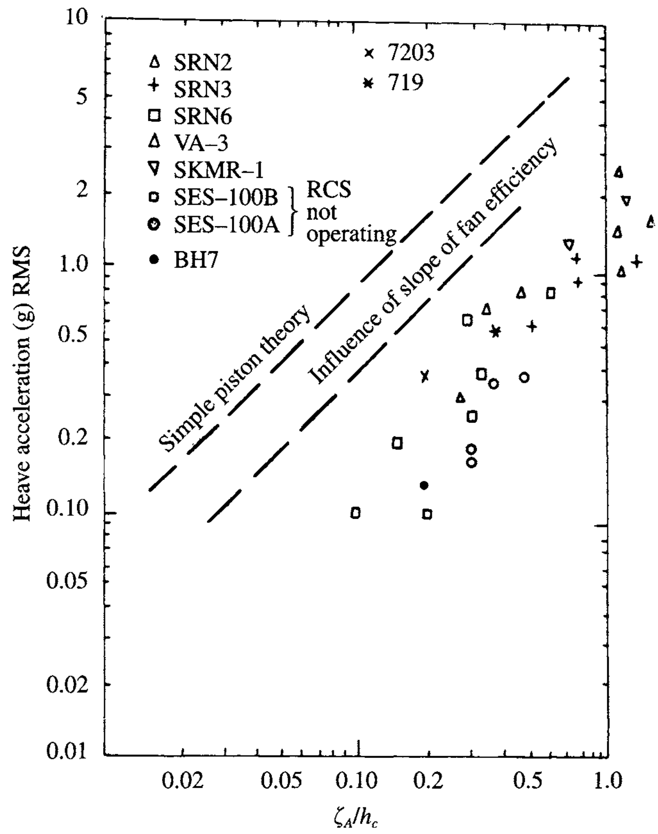

Fig. 10.8 Vertical acceleration of ACV/SES in waves.

various hovercraft (models) collected by Peter Mantle of the USA [4] and stipulates approximately the permitted vertical acceleration for SESs operating within 30 minutes and 1 day. Figure 10.9 shows the test data plotted over the ISO recommendations for human exposure to vibration. Figure 10.10 shows the vertical acceleration frequency response of a typical SES.

The so-called 'cobblestone' effect, i.e. the vertical motion of craft at high speed with high frequency, can be clearly seen. This motion tends to annoy passengers. Figure 10.11 shows the physiological response of a human being at various vibration frequencies and accelerations, which reflect the seasickness sensitivity of humans. Figure 10.12 shows the ISO regulation with respect to the vibration frequency and vertical acceleration, namely ISO standard 2631. Many users take this as the criterion to evaluate habitability of ACV/SES, namely, the operators or users may demand that the hovercraft should meet the requirements of ISO 2631 (certain acceleration level at a given operation).

Designers have to make efforts to satisfy this condition in the calculation of vertical acceleration for designing craft. Figure 10.9 shows the statistical values of vertical acceleration of some British, American and Chinese ACV/SES. From the figure one can see that the ride comfort of ACV/SES (i.e. the vertical acceleration of craft) is

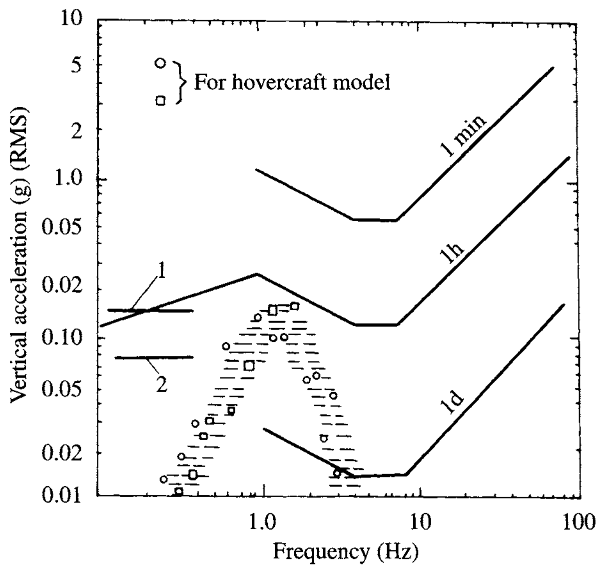

Fig. 10.9 The criteria for ride characteristics: (1) acceptable maximum accleration for SES operating on 30 min journey; (2) acceptable maximum acceleration for SES operating for 1 day.

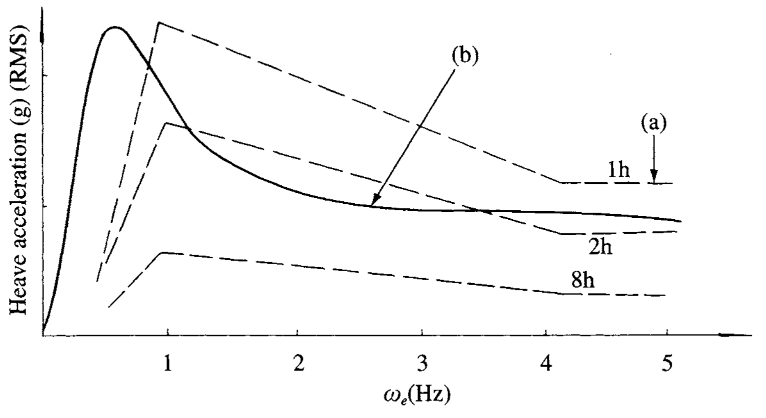

Fig. 10.10 Vertical acceleration for a typical SES in waves: (a) fatigue and efficiency reducing boundary proposed by ISO; (b) response for a typical SES in waves.

rather unsatisfactory at present for journey durations longer than 1 hour, compared with the requirements proposed by the ISO. Further development of responsive skirts for ACVs and ride control systems for SES is therefore required to enable such craft to be fully comfortable for long duration missions.

So far as ACV/SES operating in coastal or estuarine areas are concerned, such as craft weighing 30–100 t, cushion depth 1.5–2.0 m operating in a significant wave height of 0.8–1.0 m (AP1.–88, HM.2, HM.5 of UK and 719-II, 716-III and 7203 of China), the extreme vertical acceleration will be up to 0.2–0.4g and according to the requirement of the IMO, they can therefore only be operated at short range or in

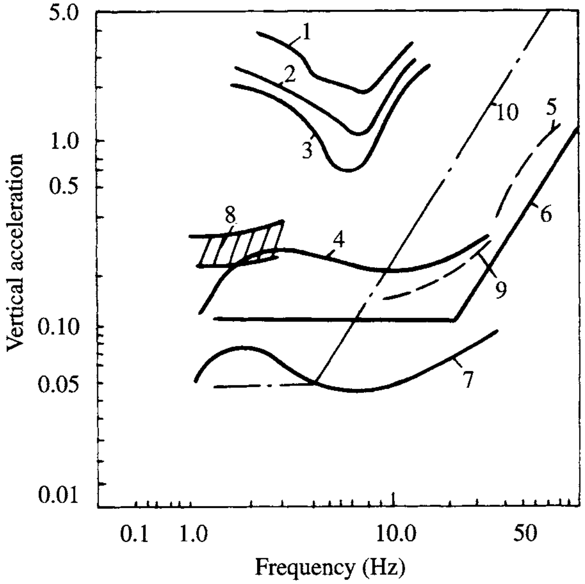

Fig. 10.11 Comfort boundaries of vibration for human being: (1) acceptable level for short time duration; (2) for 1 min; (3) for 3 mins; (4) for 4–20 mins; (5) sight quality reduced rapidly; (6) tolerable for long time duration; (7) comfort limit; (8) vertical acceleration of a typical military ACV in two sea states (weighing 50t); (9) reduced aiming; (10) reduced attention (traced photo).

protected environments, i.e. at the range of 1–2 hours, otherwise passengers will find the motion one uncomfortable.

However, the cobblestone effect also seriously influences the habitability of ACV/SES and thus affects the users' acceptance of hovercraft, because on conventional ships and high-speed catamarans motions are very small while they are running in short waves.

If automatic control systems for improving seaworthiness are applied to the craft, such as the heave attenuation system of US Navy SES-200 or Norwegian Navy MCM SES craft or the automatic control system based on inclined rudders for reducing the roll amplitude of British SES ferry HM.5, then the situation can be improved significantly. For this reason, automatic control systems form an integral part of the design of modern SESs.

Table 10.3 shows the passenger numbers with seasickness on ACV SR.N4 and Table

Table 10.3 The percentage of passengers with seasickness on SR.N4 in operation [89] (measured value)

Wave height	Acceleration (g)	Seasickness among passengers (%)
0.00–0.27	0.0–0.1	0.05
0.31–0.58	0.1–0.14	0.0
0.61–0.88	0.14–0.20	1.1
0.92–1.19	0.20–0.35	0.22
1.22–1.49	0.35–0.50	0.54
1.53+	0.52+	10.3

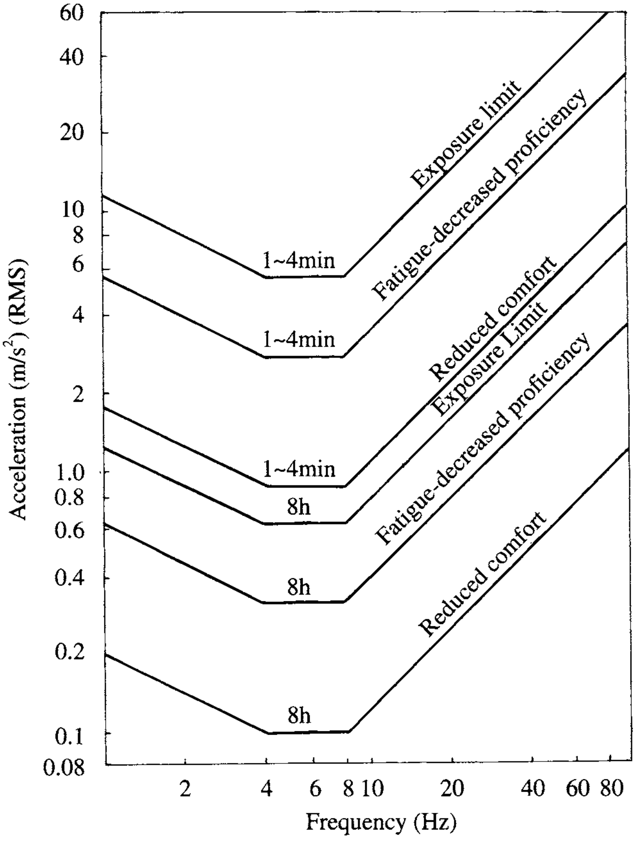

Fig. 10.12 ISO 2631 for toleration limits for acceleration/frequency.

Table 10.4 Motion standards for the surface warships

Subsystem	Motion	Significant single amplitude	Location
Crew	Roll	8°	LCG
	Pitch	3°	LCG
	Vertical acceleration	0.4g	Bridge/wheelhouse
	Lateral acceleration	0.2g	Bridge/wheelhouse
Helicopter	Roll	5°	LCG
	Pitch	3°	LCG

10.4 shows the motion standard for surface warships; thus it can be seen that the seaworthiness of ACVs needs careful design by incorporation of responsive skirts.

Noise

Nowadays there are no regulatory requirements for ACV/SES, but the high internal/external noise level of ACV/SES in comparison with conventional ships has been and still is one of the principal reasons for preventing or limiting ACV/SES penetration into the market [190]. This is why ACVs cannot operate in Hong Kong, Germany and the Netherlands without special dispensations being granted by the authorities.

Figure 6.4 shows the slogan protesting at the arrival of the British AP1.88 ACV in Germany when it went on trials for a ferry company.

Hong Kong island is so small that the ACV terminal could only be set up close to downtown Hong Kong, therefore ACVs will be not permitted by the Hong Kong government to operate near the island. Fortunately after making considerable design efforts through the 1980s and early 1990s, both the internal and external noise levels have been significantly reduced for amphibious ACVs.

The following factors influence noise levels in cabins.

General arrangement

The internal noise level can be reduced if the noise source, such as the main engines, fans and air propellers, can be separated from the passenger cabins either by isolation or by distance.

The isolation of cabins

Machinery bays with remote control and passenger cabins with noise insulation are suggested to improve noise levels.

Insulation (1). Fine noise damping and noise-absorbent material have to be used as isolation material in passenger cabins.

Insulation (2). Some noise isolation and vibration isolation measures should be adopted in the cabin areas close to the propellers.

The noise source in cabins should be decreased as low as possible

If some noise source might be located in passenger cabins, for example gearboxes and hydraulic pipelines, then they have to be isolated with a noise insulation.

Vibration damping

Mounting of main and auxiliary engines by vibration dampers should be considered.

After making efforts to reduce noise level, such as reducing the noise level of gearboxes and hydraulic pipelines, vibration isolation for the main engines, packing the volute of centrifugal fans with isolation material, etc. the cabin noise level can be reduced to under 70 dBA (Table 10.5).

After making efforts to reduce noise, the cabin noise of SES version 717 also dropped more than 10 dBA to 79 dBA. If the bow fan is not operated then the cabin noise in the navigation cabin and the fore part of passenger cabins can be reduced to

Table 10.5 The noise level at various positions on a number of craft

	Craft					
	HM.2 Mk 2	HM.2 Mk 3	717A	717C	719	719-II
Measurement position						
Middle of passenger cabin	94	83.5	93	75	85	73
Front of passenger cabin	96	83		83		
Rear of passenger cabin	93	86.5		80		
Bridge/wheelhouse	92	80.5	94	89	80	65

under 70 and 76 dBA respectively. Thanks to installing carpets, sound-absorbing plates and other sound-absorbing measures in passenger cabins, thc noise level was reduced 5 dBA from the rear part to side part of cabins with only 2.5 m of space between them.

So far as the passenger SES with steel hull version 719 is concerned, after a series of measures had been taken, the noise level of passenger cabins and navigation cabin was reduced by 12 and 15 dBA respectively, to reach the low noise level of 65 dBA. Such measures included packing the volute of lift fans by isolation material, sound-insulated passenger cabins, vibration isolating engine mountings and thickening the sound-tight layer of passenger cabins, etc.

These noise levels may be compared with modern high-speed catamarans for passengers and vehicles, in the 40–70 m class. Typically passenger cabin noise levels are 70–75 dBA. When sound levels are at this level in passenger areas, the vibration of engines and gearboxes becomes more noticeable than the noise. Once the cabin has a significant number of passengers, the noise of their conversation will tend to mask machinery vibration.

With respect to the ACV, thanks to the use of such measures and in addition using ducted air propellers and coating the duct with viscous elastic sound-absorbent material, the noise level in passenger cabins also drops noticeably.

Noise levels in the passenger cabins of small ACVs version 711-IID, 7202, etc. are approximately 90–95 dBA, but with the measures mentioned above implemented, the noise levels of passenger cabins of updated Chinese ACV versions 7210 and 716-II (ACV weighing 20 t) etc. dropped to approximately 80 dBA. While acceptable for short journeys, these noise levels need further reduction. Recent studies by some manufacturers of utility ACVs have shown that by attention to detail, noise levels in the range of 75 dBA are practical for an amphibious ACV. This progress on noise reduction is encouraging and demonstrates that the disadvantages of ACV/SES with high internal noise level can be lessened with effort.

Figure 10.13 shows the comparison of noise level in cabins between hovercraft and other forms of transport, thus it can be seen that they are close to each other. With respect to the external noise level, there are no large differences between SES and conventional high-speed craft, but the external noise of an amphibious ACV is higher than other craft because it uses air propellers. The critical problem is reducing the air velocity at the propeller blade tips. For example, originally the velocity at blade tips of British ACV version SR.N6 was about Mach 0.86. After taking some measures such as replacing the single air propeller by double propellers to reduce the blade loading, the velocity at blade tips dropped to Mach 0.49, which resulted in the air noise level reducing by about 15 dBA. In addition, the uniformity of inflow to the air propellers and distributions in the downstream of the air propellers will also affect the propeller noise. In recent years ducted air propellers have been more widely used on ACVs and give a reduction of about 6 dBA of noise. In beam winds additional noise due to the non-uniformity of air inflow may result.

As yet there are no definite standards for the noise level in cabins of ACV/SES and designers normally take the requirements from operators into account in design, together with ship's rules. Table 10.6 shows the rules for cabin noise of various ships for reference. Table 10.7 lists the noise level in the passenger cabin of some Chinese and Western ACV/SES.

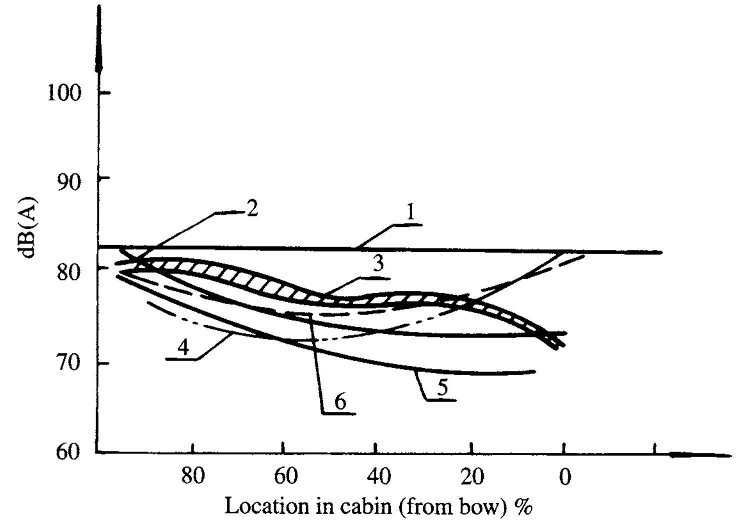

Fig. 10.13 Comparison of internal noise between hydrofoil craft, ACV/SES and various transportation forms: (1) internal noise for bus with 47 seats at speed of 90 km/h; (2) noise in the lower cabin of a jetfoil; (3) cabin noise for four-engine wide body aeroplane at cruising speed; (4) internal noise for 1980 Mazda station wagon at 90 km/h; (5) noise in upper cabin of jetfoil; (6) cabin noise for SES model 717.

Table 10.6 The rules for cabin noise level on the ships of various countries

	Country			
	UK	Japan	USA	Germany
Effect date		01.07.75	01.03.68	01.06.68
Suitable range	Shipping	Ships < 3000 t	Merchant ships	Ships with German crews
M/C room control area continuous	75	75		
M/C area non-continuous	110			110
M/C area continuous	90	85	90	90
Accommodation	60	60–65	56	65
Navigation cabin	65		65	60
Bridge	68			65
Radio room	60			60
Kitchen	70			
Recreation areas	75			
Dining rooms	75			65
Unsheltered deck	75			
Corridors	80		61	

Table 10.8 lists the requirement for external noise level in the UK. The external noise levels for Chinese ACV model 711-IID are 95 dBA at 80 m from the air propellers, and 62 dBA at 150 m, thus it can be seen that 711-IID is able to meet the UK requirement, because of the low tip velocity of the air propeller blades.

Table 10.7 The passenger cabin noise level for some high performance vehicles (dBA)

Craft	Hydrofoil	Hydrofoil	717C	719	719-II	711-IID	Griffon	AP1.88	W 120		
Type	Built 1960	Design	SES	SES	SES	ACV	ACV	ACV	Catamaran	Rules	Rules
Country	China	China	China	China	China	China	UK	UK	Norway	USSR	Japan
Measurement position											
Machinery bay	118	118		122	114		102			90–95	95
Front of passenger cabin	105–107	73	83	85	73	95		88	72	50	70–80
Rear of passenger cabin	110	80	80	98	80			88	79		
Bridge/wheelhouse		63	89	80	65		85	78		55–60	65

Table 10.8 Classification for external noise level in the UK

Location for measured points	Noise level (dBA)	Classification
152 m from ACV	70	Quiet
	80	Medium
	100	Noisy
	105	Very noisy

10.6 Requirements for manœuvrability

Since there is no difference in the manœuvrability between the SES and conventional fast boats as well as catamarans, the requirements discussed in this paragraph are for ACVs. The design issues for manœuvrability of an ACV are outlined below.

The turning diameter of an ACV at high speed

It is normal for an ACV to have sufficient turning moment from its rudders to spin the craft while travelling in a given direction. Turning is therefore a matter of generating a given side-slip while maintaining power. Assuming that this does not create stability problems, the turn radius is controlled by the thrust as a proportion of the craft total mass. The main design issue is for the designer to determine the safe envelope of operation for the craft (speed, sea state, wind, maximum safe rate of turn). If a craft may be operated safely at maximum speed with a side slip of 90°, the thrust will determine turn radius at the given speed. Determination by analysis or model tests of the maximum safe angle of side-slip in the design sea state will therefore give advice on the craft's safe operation envelope.

The course-keeping ability and handling of craft at post-hump speed

ACV downwind and down-wave performance is the most critical issue. Since control forces depend on propulsor thrust level and an ACV is normally aerodynamically stable facing into the wind, it will normally tend to broach to if power is reduced, and come off hump. The ability to trim the craft well bow up helps minimize this, so elevators can be useful in this respect. Intermittent application of power can assist, as can tacking across the wind.

In calm conditions above hump speed, ACVs are sensitive to application of control forces. If a prototype shows instability (not able to travel in a steady straight line) it may be necessary to increase the effective vertical fin area at the stern (see guidelines in Chapter 6).

The course-keeping ability of an ACV under quartering or beam winds

In side winds an ACV will operate with a steady yaw angle (or rotated pylons in the case of craft such as the SR.N4). This is not usually a problem until the craft has to perform slow-speed manœuvring at a hoverport or other special requirements, for example, the capability of an ACV running into landing craft dock, etc. Improvements for slow-speed manœuvring can be made by installing rotating bow thrusters, or rotating propeller pylons. Hoverport design can also assist craft operation [91].

Table 10.9 Capability for obstacle clearance, climbing banks and clearing canals [48]

	Obstacle width/L_c	Obstacle height/H_c	Required speed Fr
I Landing on bank			
1. Steep bank, approach vertical bank from at least 5 craft lengths	Unlimited	0.8	0.6–0.8
2. As 1, but slope 1/ 1.4	Unlimited	1.0	0.6–0.8
3. As 1, but slope 1/ 2	Unlimited	1.6	0.6–0.8
4. As 1, but slope 1/ 3	Unlimited	2.5	0.6–0.8
II Launch from bank to water			
1. Sharp bank approach vertical bank from at least 6 craft lengths	Unlimited	1.2	0.8–1.1
2. As 1, but slope 1/ 1.4	Unlimited	1.6	0.8–1.1
3. As 1, but slope 1/ 2	Unlimited	2.5	0.8–1.1
4. As 1, but slope 1/ 3	Unlimited	3.3	0.8–1.1
III Obstacle clearance			
1. Steep obstacle	Unlimited	0.7	0.6–0.8
2. Smooth bump	Unlimited	0.6	0.6–0.8
IV Clearing Ditches			
1. Rectangular ditches	0.00–0.05	Unlimited	0.6–1.7
	0.05–0.1	1.6	0.8–1.3
	0.1–0.3	0.8	0.8–1.3
	0.3–0.5	0.7	0.6–1.1
	0.5–1.2	0.4	0.6–1.1
	1.2–1.4	0.7	0.6–1.1
	1.4 +	0.8	0.6–1.3
2. Ditches with sides sloped about 1/6	0.0–0.1	0.5	1.1–1.3
	0.1–0.7	0.8	1.1–1.3
	0.7–1.0	1.0	1.1–1.3
	1.0–1.3	1.5	1.1–1.3
	1.3 +	1.6	1.1–1.3
3. As 2, but slope 1/12	0.0–0.1	0.4	1.1–1.3
	0.1–0.7	0.6	1.1–1.3
	0.7–1.0	0.8	1.1–1.3
	1.0–1.3	1.0	1.1–1.3
	1.3–2.3	1.2	1.1–1.3
	2.3 +	1.6	1.1–1.3

The manœuvrability of an ACV operating on ice

ACV drag over ice is governed by aerodynamic drag. Reduced skirt drag can allow much higher maximum speeds. This can also affect trim, due to aerodynamic lift effects. The control surfaces will be relatively more powerful and so the craft will be more sensitive to drive. Slowing and stopping will also take longer. Once again the principal design issue is to identify the safe operational envelope for craft rate of turn, side-slip, etc.

In recent years, the development of control surface design has been very innovative, so a number of control surface types and mechanisms are available for designers' selection. The requirements of manœuvrability of an ACV are a trade-off since additional installed power tends to reduce transport efficiency. Designers can select several optional layouts based on the requirements of users, then make computer analysis and free-flying model tests to make a final decision.

10.7 Obstacle clearance capability

The obstacle clearance capability of an ACV is almost completely dependent on the skirt height; ref. 48 gave some test data for reference as shown in Table 10.9. Based on these data and the requirements for obstacle clearance capability of prospective users, designers can specify the skirt height of an ACV.