Stability of small crafts
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Stability issues, general

Stability: the ability of the craft to resist the heeling moments affecting to the craft. The moments are typically induced by:

- Wind;
- Waves;
- Person shifting in the boat;
- Shifting of cargo;
- In fishing boats, forces from trawls etc.
- others
Stability & water ingress

- Because insufficient stability can lead to capsizing ands/or swamping (filling with water), prevention of water ingress is connected to the stability issues.

- This area includes
  - Position of downflooding openings
  - Position and tightness of the closing appliances
  - Systems or arrangements to remove water from decks and cockpits, or even bilge.
Hull geometry

- Large $A_X - B_{WL} \cdot T_C$ ratio: increased form stability
- Large $C_P$: increased longitudinal stability
Range of positive stability
ISO 12217

An international stability standard ISO 12217 has been developed for small craft; used extensively for leisure boats, but increasingly also for workboats below 24 m.

ISO 12217 includes three parts:
Part 1: Non-sailing boats of hull length greater than or equal to 6 m
Part 2: Sailing boats of hull length greater than or equal to 6 m
Part 3: Boats of hull length less than 6 m

Because of the versatility of the deck arrangements in boats, six different evaluation options have been established. Strengths and weaknesses of different arrangements are taken into account in these options.
Differences with ship stability

- Large passenger/crew weight compared to displacement
- Frame shape: no vertical sides → $GZ = GM \sin \phi$ is generally not valid; chine above WL at small angles → nonlinearity
- Waterplane shape, small L/B → small longitudinal stability, trim changes as function of $\phi$ has to be taken into account
- In power boats: GM typically large, openings restrict the range of positive stability
- In sailing boats:
  - with ballast keels low CG, large range of positive stability;
  - in dinghies the effect of hiking crew → unsymmetric stability curve
- $GZ$ at higher angles is affected by:
  - Hull shape
  - Deck edge immersion
  - Chine raising above water
  - In open boats water ingression over freeboard (side).
Design categories

*Design categories* describing the wave and wind conditions are an essential part of the standard. Compared to RCD, some additions have been made:

D – boats designed to operate in typical steady winds of Beaufort force 4 or less and the associated significant waves heights of up to 0,3 m and occasional waves of 0,5 m height (sheltered waters; *gusts to 12 m/s*)

C – boats designed to operate in typical steady winds of Beaufort force 6 or less and the associated significant waves heights of up to 2 m (coastal waters, bigger lakes; *gusts to 18 m/s*)

B – boats designed to operate in winds of Beaufort force 8 or less and the associated significant waves heights of up to 4 m (offshore; gusts to 27 m/s)

A – boats designed to operate in winds of *less than Beaufort force 10* and the associated significant wave heights 4,0 m (ocean; *gusts to 32 m/s*)
Downflooding openings in power boats

- Planing hulls normally wide, good stability
- Downflooding openings often critical
- Requirements for the locations and watertightness of Downflooding openings
- Typical Downflooding openings: air intakes, through-deck fittings of cables and hoses
- Open sterns, pure watertightness of engine hatches, and low (or missing) sill heights problematic when stern to wind
Different options for Conformity assessment

- Depending on the Design category and deck arrangement
- In design categories D and C a sufficient safety level may be achieved by
  - Adequate flotation if swamped
  - Adequate freeboard height (preventing water ingress)
  - Adequate decking or covering (f.ex. partially protected, hard-top boats)
- In category A and B fully enclosed decks are required (except in cat. B if sufficient flotation volume is provided, ref. RIBs)
- Stability assessing methods:
  - For small boats, normally by practical tests:
    - Freeboards at maximum load (Downflooding height)
    - Offset load test
    - Flotation test in swamped condition, typically below 6 m boats
  - For larger boats, sufficient stability is determined by calculations.
Stability assessment, ISO 12217

Table 3 — Tests to be applied to non-sailing boats < 6 m

<table>
<thead>
<tr>
<th>Option</th>
<th>1&lt;sup&gt;a&lt;/sup&gt;</th>
<th>2</th>
<th>3&lt;sup&gt;a&lt;/sup&gt;</th>
<th>4</th>
<th>5</th>
<th>6&lt;sup&gt;a&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Applicable to length of hull</td>
<td>Up to 6.0 m</td>
<td>C and D</td>
<td>C and D</td>
<td>D</td>
<td>C and D</td>
<td>D only</td>
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<td>Categories possible</td>
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<td>Any amount</td>
<td>Any amount</td>
<td>Any amount</td>
<td>Any amount</td>
<td>Any amount</td>
</tr>
<tr>
<td>Applicable to engine powers of</td>
<td></td>
<td>Any amount</td>
<td>Any</td>
<td>Any</td>
<td>Any</td>
<td>Inboard engines only</td>
</tr>
<tr>
<td>following types of engine installation</td>
<td></td>
<td>Any</td>
<td>Any</td>
<td>Partially decked&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Any</td>
<td>Any</td>
</tr>
<tr>
<td>Decking or covering</td>
<td>Any amount</td>
<td>Fully decked&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Any amount</td>
<td>Partly decked&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Any amount</td>
<td>Any amount</td>
</tr>
<tr>
<td>Downflooding-height test</td>
<td>6.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Offset-load test</td>
<td>6.3</td>
<td>6.3</td>
<td>-</td>
<td>6.3</td>
<td>6.3</td>
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<tr>
<td>Flotation standard</td>
<td>Level</td>
<td>-</td>
<td>See 6.6</td>
<td>-</td>
<td>-</td>
<td>Basic</td>
</tr>
<tr>
<td>Flotation test</td>
<td>6.4</td>
<td>-</td>
<td>See 6.6</td>
<td>-</td>
<td>-</td>
<td>6.5</td>
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<tr>
<td>Flotation elements</td>
<td>Annex C</td>
<td>-</td>
<td>Annex C</td>
<td>-</td>
<td>-</td>
<td>Annex C</td>
</tr>
<tr>
<td>Capsize-recovery test</td>
<td>-</td>
<td>-</td>
<td>6.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

<sup>a</sup> Boats using options 1, 3 and 6 are considered to be susceptible to swamping when used in their design category.

<sup>b</sup> This term is defined in 3.1.5.

<sup>c</sup> This term is defined in 3.1.6.

<sup>d</sup> This test is not required to be applied if, when swamped during the test described in 6.4, the boat supports an equivalent dry mass of 133% of the maximum total load, or if the boat does not take on water when heeled to 90° from the upright in light craft condition.
Power- and rowing boats – open boats with floats

L < 6 m boats, ISO 12217-3 option 1
- Assessed by freeboard height (0.2m), offset load test and flotation test
- Floating when swamped
- Design category D (or C, higher requirements)

L ≥ 6 m boats, ISO 12217-1 option 4
- Freeboard (Lh/20, +15% at bow) + offset load + flotation test
- Floating when swamped
- Design category D or C
Power- and rowing boats – open boats without floats

For 4,8 - 6 m boats ISO 12217-3 option 5
- Assessment by freeboards + offset load test
- Only for design cat. D
- No floats; higher requirements for freeboards (0.4 m) and stability

For 6 m and larger boats ISO 12217-1 option 6
- Freeboards (Lh/10 +15% at bow) + offset load test + downloading openings location and watertightness
- Design.cat. D or C
- No floats
Powerboats – Fully enclosed Rigid inflatable boats (RIB)

- Assessment by reserve buoyancy and offset load test. Separate requirements for the material and structure of the pontoons (ISO 6185).
- Possible design categories D, C and B
Powerboats – partially protected, "2/3 decked"

For 4.8-6 m boats ISO 12217-3 option 4
- Freeboards (cat.C Lh/12, cat.D Lh/14) + offset load test + downlooding openings location and watertightness
- Design.cat. D or C
- No floats
Fully enclosed (decked) powerboats

L < 6 m boats ISO 12217-3 option 2
- Freeboards (Lh/17) + offset load test + downlooding openings location and watertightness

L ≥ 6 m boats ISO 12217-1 option 1 and 2
- Design categories C ja D
  - Freeboards (Lh/17) + offset load test + wind induced heeling + downlooding openings location and watertightness
- Design categories A and B
  - Freeboards (Lh/17) + offset load test + downlooding openings location and watertightness + dynamic stability assessment based on GZ-curve
Open sailing boats without floats

Below 6 m open sailing boats cannot be certified according to ISO 12217.
L ≥ 6 m boats ISO 12217-2 option 2, 3 or 5, based on either:

- Adequate stability (sail area compared to stability), or
- Self-righting ability when the mast top touches water surface (knockdown recovery test), or
- Adequate stability index (STIX)
- Design categories D or C only.
Sailing boats with floats

For < 6 m boats the following alternatives according to ISO 12217-3:
- Option 7a, capsize recovery test
- Option 8a, knockdown recovery test
- Option 9a, wind stiffness, stability calculation
- Design categories D or C only.

For ≥ 6 m boats:
- Option 4, knockdown recovery test
- Option 6, wind stiffness calculation
- Design categories D or C only.
Decked sailing boats

For < 6 m decked (fully enclosed) boats the following alternatives are possible according to ISO 12217-3:

- Option 10, knockdown recovery
- Option 11, wind stiffness calculation
- Categories C & D only

For L ≥ 6 m boats ISO 12217-2 is used, assessment based on stability index (STIX) and GZ-curves.
Cocpits and recesses

Any volume open to the air that might retain water within the range of loading conditions and corresponding trims. Typically cockpits, wells, open volumes or areas bounded by bulwarks or coamings, but also f.ex. anchor boxes if it cannot be closed weather-tight.

Because the water gathered to recesses is dangerous from the stability point of view, there is requirements for maximum size, draining time, tightness and companionway openings.
Openings and their closing appliances

- Boats have many different openings, others with closing appliances (windows, portlights, hatches, deadlights, doors, sliding appliances, escape hatches, underwater through-hull fittings), others without them (engine air intakes, heater funnel, lämppärin korsteeni, through-hull fittings clearly above water).

- These have high influence on safety against water ingress. The following points shall be considered, depending if it is closed or open at sea:
  - If kept closed when under way, then:
    - Watertightness
    - Strength
  - If occasionally or always open when under way, then in addition to the previous:
    - Location
    - Design category
    - To which room the opening is leading
Accidents according to statistics 2007-09 in Finland

- Fatal boat accidents are related to persons falling in water, sinking or swamping of the boat, or fire
- Boat accidents have two main phases:
  1. Accident that leads to person(s) in water;
  2. Rescue
- According to the statistics, the majority of the fatal accidents are connected with stability issues
- However, it shall be remembered that the vast majority of the accidents are happening for small row- and powerboats.
- In an old more thorough investigation 1989 the conclusion was the same
Accident scenarios

1. Capsizing, remains floating
   - Probable only, if the boat has watertight compartmentation or floats
   - Special case: Sailboat loosing her keel, capsizes immediately and remains floating upside down for a while

2. Capsizing and sinking
   - In other cases than 1, the boat gradually fills with water and sinks

3. Swamping and capsizing
   - The boat looses stability because of leaking water and finally capsizes. May remain floating if there is airtight compartments or floats as in case 1.

4. Swamping and sinking
   - More probable is that the boat is finally sinking.
Some comments on the design trends

- Very large recesses
- Recesses also in the bow: Bowriders
- Open sterns
- Boats that seem to be decked (fully enclosed), but are not
- Low freeboards, especially at the bow
- Difficult access to closing appliances, pumps etc.
- Ridiculous bilge pumps
- Large, badly designed, leaking engine hatches

Stability issues shall be emphasized again!