Abstract Heading
The American Bureau of Shipping (ABS) has published a series of Guides for habitability and comfort at sea, including: crew and offshore habitability, and passenger comfort. The Guides represent a significant step forward in the development of classification standards that will help improve maritime safety by reducing crew fatigue. One aspect of the Guides development process are activities to verify and validate the content of the Guides in terms of (1) criteria imposed, (2) data collection processes and methods, and (3) interpretation of findings in rendering decisions to grant habitability notations. While it has been established that the requirements in the various Guides perform well with regard to being consistent with environmental conditions noted at sea, the larger question remains whether established standards (ISO, Classification Societies, etc.) are suitable for promoting human comfort. This paper discusses and presents the current criteria and guidance, experience gathered from validating those criteria aboard ships and offshore structures, and provides assessments as to the validity and the utility of the criteria to facilitate comfort.

Keywords
Ergonomics, whole-body vibration, noise, temperature, humidity, task lighting, habitability, mariner comfort, human fatigue management.

Introduction
The ABS Habitability Guides are provided to help improve maritime safety by reducing crew fatigue (crew performance) and enhancing quality of life at sea. One aspect of the Guide's development process are activities to verify and validate the content of the Guide in terms of (1) criteria stated, (2) data collection processes and methods, and (3) interpretation of findings in rendering decisions to grant habitability notations. In continuation of this verification and validation activity, ABS representatives have visited numerous ships and offshore structures to measure the accommodations and the ambient environmental characteristics of crew working and living spaces. The ambient environmental characteristics measured are human whole-body vibration (WBV), noise, indoor climate, and lighting. The objectives of the validation trials were to:

- Measure the ambient environmental conditions onboard using the procedures and guidance provided in the Guide
- Evaluate the measurement procedures and methods as expressed in the Guide
- Identify any difficulty in executing measurement procedures and recommend improvements for future revisions of the Guide
- Validate criteria contained within the Guide
- Provide an indication to the owners/operators of the structures visited of the level of compliance with the requirements of the Guides.

Guides currently offering notations for compliance exist for passenger comfort, crew habitability, and offshore installations. The current Guides are not specific to differing vessel sizes.

Criteria and requirements for all sections in the Guides were culled from a wide range of industry and international standards. Weight and preference were applied to standards and guidance documents specifically related to maritime applications. Every requirement in the Guides has a source in the industry or international standards used.

In the course of assessment and validation, accommodations checklists were applied and direct measurements were carried out for each ambient environmental requirement contained in the ABS Guides. Measurements were carried out on passenger ferries, tankers, offshore supply vessels (OSVs), Mobile Offshore Drilling Units (MODUs), offshore crew boats, and passenger vessels.

Measurement data collected were then compared to the criteria contained in the various Guides. Following are summaries of the findings for accommodations and for each ambient environmental characteristic.
**Accommodations**

One of the more influential factors for supporting human performance and reducing human errors is suitable facility design. The quality of the accommodations where ship’s crew sleep, eat and relax will influence job performance and each individual’s overall sense of comfort and well being. Suitable facility design should not be aimed at just maintaining minimal health levels but targeted to support reliable seafarer performance and comfort.

Based on visits and the conduct of accommodations assessments, the accommodations are generally suitable to facilitate comfort, sleep, and mariner provisions. It was noted that available space considerations for smaller vessels may require some of the size/space related accommodations criteria to be modified.

**Indoor Climate**

Measurement results of temperature and humidity, with few exceptions, for all vessels visited, generally met the Guide’s criteria related to temperature and humidity. In no case, however, were ships visited in extreme conditions of cold or heat. For all ships visited, it was deemed that the criteria and methodologies within each Guide were reasonable and achievable.

For all ships and offshore installations visited, it was deemed that the indoor climate criteria and methodologies within each Guide were reasonable and achievable.

**Lighting**

Deviations from the Guide’s lighting criteria were identified in all ships visited, and non-compliances occurred on a space-by-space basis. Some deviations were the result of the crew intentionally removing elements from the lighting fixtures, or by not turning on all the lights in that space, due to glare or personal preference. In other cases, inadequate light levels were evident as a result of design, for example, deviations in some galleys were attributed to the design of galley lighting fixtures, placement, and light emitted.

For all ships and offshore installations visited, it was deemed that the criteria and methodologies within each Guide were reasonable and achievable, however, some minor modifications to lighting criteria are being considered based on additional guidance recently published (NORSOK, 2004).

Based on visits to Offshore Supply Vessels (OSVs), lighting criteria were added related to OSV Deck and Cargo Handling Areas.

**Noise**

Numerous exceptions from the criteria in the Guides were noted on all ships visited. Generally, the magnitudes of these exceptions were only at a few decibels, and there were cases of large deviations. A main contributor to noise levels leading to exceeding criteria tended to be ventilation system design at the ducting.

For all ships and offshore installations visited, it was deemed that the criteria and methodologies within each Guide were reasonable and achievable, however, since the Guides were originally published recent noise criteria and recommendations from the International Maritime Organization (IMO) have been published, and the noise criteria in each Guide is under review. The IMO requirements for noise are slightly higher than those required of the existing ABS Guides, and the ABS Guides will be selectively modified according to IMO guidance.

**Whole-Body Vibration**

For large vessels visited and for which measurements were taken, vibration levels in manned crew spaces were generally within the limits stated in the Guides. Most of the required sea and operating conditions in the Guide for the measurement of human whole-body vibration were met with the exception of typical Sea State levels for floating structures on a MODU visit.

While exceptions to the ABS criteria were found for noise, lighting, and indoor climate, these generally were not significant departures and many cases seemed potentially remediable. With respect to whole-body vibration, the larger ships visited were generally found to meet the ABS requirements for human whole-body vibration. For smaller vessels (OSVs, crew ships) there was a reduced level of compliance with whole-body-vibration criteria.

There is also some disagreement within the ergonomics community as to what constitutes a suitable measurement of human comfort and exposure to whole-body vibration (WBV). One contentious area is the selection of the frequency weightings to be used to compute a value of WBV experience and exposure.

**What are Comfortable and Tolerable Levels of Whole-Body Vibration?**

Given that the performance of ships with regard to noise, temperature, humidity and lighting were generally at or within the requirements of the Guides, and given that the performance of the ships with regard to WBV were typically compliant with the Guides for larger ships, however, and given the controversy as to what constitutes acceptably comfortable levels of vibration, the remainder of this paper emphasizes discussion of the issues related to WBV and its measurement. Recalling that this paper discusses human comfort, and not health hazards associated with vibration, safety and health hazards are not discussed. It is noted that it is assumed that providing a comfortable vibration environment will also provide a safe, hazard free environment.

**Whole-Body Vibration**

The immediate question is simply, “What are comfortable and tolerable levels of vibration?” Comfort can be defined...
as “a condition of ease or satisfaction of human needs,” or “the freedom from pain and concern.” Given this, “comfort” is not directly observable, it must be inferred by use of operational definitions and subjective assessment.

In studying comfort and in establishing its characteristics with regard to WBV (as well a vibration of parts of the human body, such as the arms, hands, eyes, and so on), an historic approach is to assemble a group of human research participants, arm them with definitions (a “semantic scale”) of comfort and discomfort, expose them to different levels of vibrations of differing frequencies and amplitudes, and then ask each to rate each level. A sample semantic scale for vibration comfort/discomfort follows:

- Very unpleasant
- Unpleasant
- Mildly unpleasant
- Not unpleasant
- Just Noticeable
- Not Noticeable

A participant would rate each vibration exposure according to the scale provided. After making subjective judgments, norms are identified when, for example, half of the participants state that a particular level of vibration is comfortable vs. the next adjacent level.

Where there is high consistency of responding to a particular frequency, for example, where all the participants respond in just about the same way (as, for example “Unpleasant”), it can be stated that the participants are sensitive to that frequency. Where there is consistency at a frequency (for many levels of amplitude) that is “Just Noticeable” or “Not noticeable,” then it can be stated that the subjects are not susceptible to those frequencies of vibration. From this, distributions of comfort susceptibility can be derived and used in the development of WBV frequency weighting distributions. Analytic approaches that examine part-body vibrations (e.g., hand, lower arm, etc.) can also be used when vibration and their resonances are demonstrated to be moving and torsioning those body parts. (Griffin, 1988).

Vibrations in the frequency range of 0.5 Hz to 80 Hz have significant effects on the human body. Table 1 presents a sample of the results of several of these vibration and comfort research studies. Table 2 provides examples of the effects of several levels of body discomfort and vibration frequency. Table 3 identifies some human performance issues related to exposure to vibration.

### Table 1: Comparison of Results from Four Experiments using Semantic Scales (Adapted from Griffin, 1990)

<table>
<thead>
<tr>
<th>Study</th>
<th>Scale</th>
<th>Mean magnitude (m/sec² RMS)</th>
<th>Situation</th>
</tr>
</thead>
</table>
| Fothergill (1972)    | • Very unpleasant  
• Unpleasant  
• Mildly unpleasant  
• Not unpleasant  
• Noticeable       | 2.5  
1.7  
1.1  
0.7  
0.3             | Seated subjects  
Magnitudes of 8 Hz sinusoidal vibration |
| Jones and Saunders (1974) | • Very unpleasant  
• Very uncomfortable  
• Uncomfortable  
• Mean threshold of vibration discomfort  
• Not uncomfortable | 3.7  
2.2  
1.2  
0.7  
0.33          | Seated subjects  
Magnitudes of 10 Hz sinusoidal vibration |
| Oborne and Clarke (1974) | • Very uncomfortable  
• Uncomfortable  
• Fairly uncomfortable  
[to] Fairly comfortable  
• Comfortable  
• Very comfortable | More than 2.3  
1.2 to 2.3  
0.5 to 1.2  
0.23 to 0.5  
Less than 0.23 | Standing subjects  
Magnitudes of 10 Hz sinusoidal vibration |
| Fothergill and Griffin (1977c) | • Very uncomfortable  
• Uncomfortable  
• Mildly uncomfortable  
• Noticeable, but not uncomfortable | 2.7  
1.8  
1.1  
0.4 | Seated subjects  
Magnitudes of 10 Hz sinusoidal vibration |
When considering WBV, every organ or segment of a body has a resonant frequency such that when an arm (for example) is vibrated at its resonance frequency the vibration is amplified—sometimes to as much as four times the source, or input, vibration level. Figure 1 presents the susceptibility of various body parts with regard to vibration frequency in terms of both human performance (ability to reliably do productive work) and human comfort.

Internal organs have individual resonant frequencies and do not vibrate as a collective mass.

In the ABS Guides for Habitability and Comfort, the collective vibration tolerances are considered in establishing limits for WBV.

### Table 2. Body Discomfort and Vibration Frequency (Hz).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General feeling of discomfort</td>
<td>4-9</td>
</tr>
<tr>
<td>Head symptoms</td>
<td>13-20</td>
</tr>
<tr>
<td>Lower jaw symptoms</td>
<td>6-8</td>
</tr>
<tr>
<td>Influence on speech</td>
<td>13-20</td>
</tr>
<tr>
<td>&quot;Lump in the throat&quot;</td>
<td>12-16</td>
</tr>
<tr>
<td>Chest pains</td>
<td>5-7</td>
</tr>
<tr>
<td>Abdominal pains</td>
<td>4-10</td>
</tr>
<tr>
<td>Urge to urinate</td>
<td>10-18</td>
</tr>
<tr>
<td>Increased muscle tone</td>
<td>13-20</td>
</tr>
<tr>
<td>Influences on breathing</td>
<td>4-8</td>
</tr>
<tr>
<td>Muscle contractions</td>
<td>4-9</td>
</tr>
</tbody>
</table>

### Table 3. Human Performance and Exposure to Vibration

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Human Performance and Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 Hz to 0.5 Hz</td>
<td>- The just noticeable range</td>
</tr>
<tr>
<td></td>
<td>- Motion sickness</td>
</tr>
<tr>
<td></td>
<td>- Motion Induced Instability</td>
</tr>
<tr>
<td>0.5 Hz to 15 Hz</td>
<td>- Motion Induced Instability</td>
</tr>
<tr>
<td></td>
<td>- Fatigue</td>
</tr>
<tr>
<td></td>
<td>- Abdominal discomfort</td>
</tr>
<tr>
<td>15 Hz to 25 Hz</td>
<td>- Motion Induced Instability</td>
</tr>
<tr>
<td></td>
<td>- Much discomfort</td>
</tr>
<tr>
<td></td>
<td>- Fatigue</td>
</tr>
<tr>
<td></td>
<td>- Difficult hand/arm control</td>
</tr>
<tr>
<td></td>
<td>- Vibrato speech</td>
</tr>
<tr>
<td>25 Hz +</td>
<td>- Sensations and perceptions influenced</td>
</tr>
<tr>
<td></td>
<td>- Blurred vision</td>
</tr>
<tr>
<td></td>
<td>- Task performance decay</td>
</tr>
</tbody>
</table>

**Low Frequency Vibration and Motion Sickness**

Interestingly, the word nausea is the Latin word for sea sickness and is a derivative of the word ‘naũs,’ meaning ship. The Latin ‘nautic’ pertains to ships or sailors.

Two significant factors that influence comfort in the presence of vibration are individual differences and expectations. To illustrate individual differences, the levels of tolerable or comfortable vibration to a ten year old will be much different compared to that of a senior citizen. Similarly, tolerances will vary among normally healthy 30 year-olds. People simply have different tolerances, and in the setting of standards related to comfort, allowing any level of vibration will not be satisfactory to all people. Setting of vibration standards usually is directed at satisfying a percentage of people, and that often depends on the population of people to be satisfied. For the ABS passenger comfort Guide, the criterion is set allowing for approximately 10% of males and 15% of females to experience motion sickness (females are more susceptible than males) while still being compliant with the Guide. The case of paying passengers on a cruise liner requires that a significant majority of passengers deem their environment to be comfortable, and justifies a more restrictive set of vibration criteria.
Regarding expectations, tolerance to varying levels of vibration will differ by occupation and experience to vibration through exposure. The expectations as to what level of vibration to expect on the job depend on the work environment. For example, school teachers, office workers, or hospital workers expect a level of on-the-job vibration that is lower than the expectations of those who operate machinery, fighter aircraft, or ships. It is expected that the vibration expectations of mariners are somewhat higher than those of a general land-based population, and therefore tolerance to higher levels of vibration may be deemed acceptable. There is also, in support of this statement, the fact that mariners selected this career, likely knowing the environmental characteristics of living aboard ship, including exposure to vibration and the other environmental characteristics included in the comfort and habitability Guides.

The population of experimental subjects involved in vibration and comfort research are typically land based and diverse in occupational background. This population likely possesses an “average” tolerance to exposure to vibration in terms of perceived comfort. It is from these data that frequency weighting curves, frequency band limits, and limiting amplitudes for comfort are derived. These are good predictors of general population response to vibration in terms of comfort. These limits are probably fair predictors for mariners.

Low frequency vibration, usually involving the vertical (z) axis, is associated with motion sickness (Lawther and Griffin, 1986, 1988). Motion sickness characterized by a feeling of nausea, and in extreme cases vertigo can be experienced. A significant mechanism of motion sickness is a disassociation of the senses integrated to form a perception of motion and body orientation. In other words, the primary sense of balance and orientation (formed mainly in the inner ear: called vestibulation) and other senses, principally vision and body position sensor in the muscles and joints (proprioception), are in disagreement. A main source of these disparate sensory reports (termed “vection”) result from being on a moving or unstable platform.

Sopite syndrome occurs in frequencies similar to those inducing motion sickness. Sopite syndrome is characterized by drowsiness, fatigue, difficulty in concentrating and disturbed sleep. It seems to be a form of motion sickness without nausea.

In the general population:
- 25% of population generally susceptible (27% of females, and 17% of males),
- Habituate (get over it) in about a week
- Learn to habituate
- A small (5%) never habituate.

Frequencies of vertical oscillation/vibration to which people seem to be susceptible to motion sickness are in the 0.1 to 0.7 Hz range, with 0.5 Hz being the most strongly inducing of motion sickness.

**Vibration Criteria and Guidance**

The question remains as to what levels of WBV, and the associated characteristics of that vibration (band limitations and frequency weighting) are appropriate for marine systems.

In order to help answer the questions as to what are reasonable, comfortable, and achievable levels of WBV for mariners, a comparison was made of several requirements documents that impose limits on vibration to which humans are exposed. These include:


Of these, none actually impose limits on acceptable levels of vibration, rather, they merely present typically reported levels of human comfort as a function of WBV level, and it is left to the users of these guidance documents to specify limits.

Translating guidance of this sort to recommended or required limits requires some consideration of the environments under which vibration exposure will occur, and the expectations of those exposed. As stated in ISO 2631, “...the reactions of various magnitudes depend on passenger expectations with regard to trip duration and the types of activities passengers expects to accomplish (e.g., reading, eating, writing, etc.).” ISO 2631 and BS 6841 presents the following WBV limits as guidance:

<table>
<thead>
<tr>
<th>Frequency (m/s²)</th>
<th>Comfort Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0.315</td>
<td>Not uncomfortable</td>
</tr>
<tr>
<td>0.315 to 0.63</td>
<td>A little uncomfortable</td>
</tr>
<tr>
<td>0.5 to 1.0</td>
<td>Fairly uncomfortable</td>
</tr>
<tr>
<td>1.25 to 2.5</td>
<td>Very uncomfortable</td>
</tr>
<tr>
<td>Greater than 2.0</td>
<td>Extremely uncomfortable</td>
</tr>
</tbody>
</table>

ISO 6954 is consistent with ISO 2631 regarding provision of guidance rather than prescribing limits. According to ISO 6954: “it is recommended that the classification to be applied to the various areas of a ship be agreed between the
interested parties (e.g., shipbuilder and ship owner), prior to any assessment of the habitability.”

Three levels of WBV guidance are provided, for passengers, crew, and work areas, in the frequency range of 1 Hz to 80 Hz, as follows:

<table>
<thead>
<tr>
<th>Values above which adverse comments are probable</th>
<th>Values below which adverse comments are not probable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger: 0.143 m/s²</td>
<td>0.0715 m/s²</td>
</tr>
<tr>
<td>Crew: 0.214 m/s²</td>
<td>0.107 m/s²</td>
</tr>
<tr>
<td>Work Area: 0.286 m/s²</td>
<td>0.143 m/s²</td>
</tr>
</tbody>
</table>

Comparing this guidance to the empirical data in Table 1, the guidance (if conformed to) would provide a very comfortable WBV environment. In fact, 0.143 m/s² is very near the threshold of perception, and many people would not sense any WBV.

Figure 2 presents the relative frequency weighting distributions for ISO Standard 2631 and British Standard 6841. Annotated on this figure are the associated frequencies of human WBV where discomfort or performance degradations are noted. Compelling in this figure, for ISO Standard 2631 and British Standard 6841, are the coincidences of highly valued/weighted frequencies with associated human susceptibility: the more significant frequencies/spectra are more heavily weighted.

With regard to band limitations, varying requirements are as follows:
- ISO 6954 (1987): 1 to 100 Hz
- ISO 6954 (2000): 1 to 80 Hz
- BS 6841 WBV (1987): 0.5 to 80 Hz
- BS 6841 Motion Sickness (1987): 0.1 to 0.5 Hz
- BS 6841 WBV (1987): 0.5 to 80 Hz
- ISO 2631: Motion Sickness (1987): 0.1 to 0.5 Hz

Given the consideration of contiguous band limitations for WBV and motion sickness of BS 6841, ABS resolved to base habitability and comfort WBV requirements on those weighting distributions, band limitations, and WBV guidance of BS 6841. These are consistent with regards to weighting of ISO 6954 (which states “the results of each measurement shall be the overall frequency-weighted r.m.s. value as defined for acceleration in ISO 2631-1: 1997.”

Table 4 presents a summary of the ABS limiting vibration requirements. Note that there are impending notations in the table suitable for smaller ships and vessels. This is in acknowledgment of the measured vibration characteristics of these vessels.

The limiting values in Table 4 are based on the recommendations of BS 6841 since it provides for a continuous measurement of vibration (WBV and Motion sickness related) from 0.1 Hz to 80 Hz – the frequencies of interest in terms of human comfort and performance.
The limiting values in Table 4 are based on the recommendations of BS 6841 since it provides for a continuous measurement of vibration (WBV and Motion sickness related) from 0.1 Hz to 80 Hz – the frequencies of interest in terms of human comfort and performance.

The acceptable levels of WBV are based on those discussed in both BS 6841 and ISO 2631 as they influence the factors of human comfort and performance. Given that the guidance allows for flexibility, depending on the environment and the expectations of users, and that the weighting distributions are more or less coincident, the ABS criteria are consistent with the intent of both guidance documents.

Further, comparing the ABS requirements with the data presented in Table 1, the ABS HAB and HAB+ requirements are squarely within the bounds of “not uncomfortable” according to all standards and the research efforts presented by Griffin. Noting those research efforts, perceived discomfort is observed at around 0.7 meter/second². The ABS requirements for a ship or offshore HAB notation of less than 0.4 meter/second² is well under this boundary.

Pending requirements for smaller craft (OSVs, Yachts) are under review and development. The WBV requirements to be imposed (if any) will continue to be consistent with the research literature related to comfort and performance, and within the intent and guidance of the British, ISO, and other standards.

**Conclusions**

Based on review of human tolerances to potential environmental stressors, a broad range of environmental guidance, requirements, and criteria related to human comfort and performance, and recognition of the special environment the sea imposes on humans and machines, ABS has developed a series of habitability criteria for the marine industry. Validation of requirements related to temperature, humidity, noise, lighting, WBV and motion sickness revealed that the only contentious and difficult requirement is related to human vibration. Requirements for the areas of noise vibration and atmospherics were found to be sound, pragmatic, and achievable with little modification.

WBV levels observed on ships and offshore structures were quite variable, and in most cases bordered the ABS requirements. Larger ships, ferries, and offshore structures generally met the WBV requirements of the Guides, however, smaller craft such as OSVs and crew boats, did not fare as well, and many would not be considered for a habitability notation.

It is considered that the ABS standards afford a more than adequate level of comfort and human performance without imposing an excessively strident demand on ship design.

**References**


### Table 4. ABS Vibration Requirements (m/s²)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship and Offshore HAB notation</td>
<td>0.4</td>
</tr>
<tr>
<td>Ship and Offshore HAB+ notation</td>
<td>0.315</td>
</tr>
<tr>
<td>Passenger COMF</td>
<td>0.315</td>
</tr>
<tr>
<td>Passenger COMF+</td>
<td>0.20</td>
</tr>
<tr>
<td>Passenger COMF+ (MSDV)</td>
<td>30 m/s¹⁵</td>
</tr>
<tr>
<td>OSV HAB Notation (Pending)</td>
<td>0.5</td>
</tr>
<tr>
<td>OSV HAB+ Notation (Pending)</td>
<td>0.4</td>
</tr>
<tr>
<td>Yacht COMF(Y) and COMF(Y) + (Pending)</td>
<td>TBD</td>
</tr>
<tr>
<td>Other Work Boats and Vessels</td>
<td>TBD</td>
</tr>
</tbody>
</table>

**Notes:**

Motion Sickness Dose Value (MSDv) units are exposure units, expressed as m/s¹⁵ which m/s² over time of exposure.

No Motion sickness criteria for ship HAB

Motion sickness (Passenger COMF+) 0.1 to 0.5 Hz

0.5 to 80 Hz for COMF and HAB notations

Frequency weightings in accordance with BS 6841

HAB+ Notation directed and crew comfort and human (job) performance

HAB Notation directed at human (job) performance

IMO Resolution A.468 (XII), Code on Noise Levels on Board Ships, 19 November 1981.


NORSOK-002. (2004). Working environment (Rev. 4)

