An assessment of the effect of variance in probe weight on the fall-rate of expendable bathythermograph and pure temperature bias

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Motivation

✓ Fall-rate of XBT seems to have changed over time.

But, what caused such change?

There’re lots of statistical estimates, but we generally lack physical explanation for them.

✓ A possible known factor is the variance in probe weight.
  (manufacturers’ tolerance in production)

  Sippican: ±5g, TSK: ±1g for total probe weight in air

Can such weight variance explain the range of suggested fall-rate variation?

How does fall-rate change with probe weight?
Purpose of this study is to investigate how (T7’s) fall-rate depends on difference in probe weight.

Strategy

Scrape a part of the metal nose of TSK T7 by a lathe to reduce its weight by 10g or 20g.

Compare the fall-rates of the modified TSK T7 with those of normal T7 manufactured by TSK and LMS.

Notes:

- A normal LMS T7 is lighter than a normal TSK T7 by about 10g (Kizu et al., 2011 → “K11”).
- So, a 10g-reduced TSK T7 approximately weighs as much as a normal LMS T7.
- The two companies’ T7 have many structural differences (K11).
Weight of parts

The 1st line is in the air, and the 2nd line is in the water (K11). The former is averages of two dozens, and the latter is from a couple of pieces.

Nose weight

<table>
<thead>
<tr>
<th></th>
<th>LMS</th>
<th>TSK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>575.6g</td>
<td>575.2g</td>
</tr>
<tr>
<td></td>
<td>(484.7g)</td>
<td>(485.1g)</td>
</tr>
</tbody>
</table>

~80% (~85%) of total weight in the air (water)

Probe wire

<table>
<thead>
<tr>
<th></th>
<th>LMS</th>
<th>TSK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>101.9g</td>
<td>113.0g</td>
</tr>
<tr>
<td></td>
<td>(76.5g)</td>
<td>(88.6g)</td>
</tr>
</tbody>
</table>

gradually paid out during fall (expires at rated depth+)

Total

<table>
<thead>
<tr>
<th></th>
<th>LMS</th>
<th>TSK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>729.1g</td>
<td>740.5g</td>
</tr>
<tr>
<td></td>
<td>(564.1g)</td>
<td>(576.5g)</td>
</tr>
</tbody>
</table>

12g (2%) for both

After-body (incl. wire spool)

<table>
<thead>
<tr>
<th></th>
<th>LMS</th>
<th>TSK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>51.0g</td>
<td>52.1g</td>
</tr>
<tr>
<td></td>
<td>(2.9g)</td>
<td>(2.8g)</td>
</tr>
</tbody>
</table>
Lightening the nose weight

3.7mm

7.6mm (for cutting 20g)
Half depth for 10g.

The alteration was made by TSK.

The gap is not filled for technical difficulty.
**Total weight of probe (grams; in the air) used in the present test**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>MIN</th>
<th>MAX</th>
<th>AVE</th>
<th>SD</th>
<th>MAX-MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TSK</strong></td>
<td>24</td>
<td>740.7</td>
<td>742.0</td>
<td>741.7</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>TSK (-10g)</strong></td>
<td>35</td>
<td>730.0</td>
<td>731.1</td>
<td>730.5</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>TSK (-20g)</strong></td>
<td>35</td>
<td>720.1</td>
<td>721.2</td>
<td>720.6</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>LMS</strong></td>
<td>22</td>
<td>728.5</td>
<td>734.2</td>
<td>731.0</td>
<td>1.7</td>
<td>5.7</td>
</tr>
</tbody>
</table>

**Similar comparison**

**Samples used in our previous test (K11)**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>MIN</th>
<th>MAX</th>
<th>AVE</th>
<th>SD</th>
<th>MAX-MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TSK (2006)</strong></td>
<td>24</td>
<td>739.8</td>
<td>741.1</td>
<td>740.5</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>LMS (2008)</strong></td>
<td>24</td>
<td>725.8</td>
<td>732.4</td>
<td>728.9</td>
<td>1.7</td>
<td>6.6</td>
</tr>
</tbody>
</table>
Weight difference between LMS T-7 and TSK T-7 (K11)

TSK T-7 is heavier by about 12g (2%) than LMS T-7.

This weight difference came from difference in weight of probe wire.

So, 10g-lightened TSK T-7 and LMS T-7 have different mass balance though they weigh the same as a total.

Structural differences (nose weight; outer shape)

Diameter: TSK T-7 is 0.2mm (0.4%) larger

Length: TSK T-7 is 1mm (1.7%) longer
Structural differences between LMS T-7 and TSK T-7 (K11)

Inside hollowing: Very different

According to the manufacturers’ info,

- All TSK’s XBT have concentric design.
- Sippican’s (now LMS)
  - T-7 and Deep Blue are non-concentric, but
  - T-4, T-5, T-6 and T-10 are concentric.

Diameter of central hole (water inlet):

TSK T-7 is 0.5 mm (4.6%) smaller
Structural differences between LMS T-7 and TSK T-7 (afterbody; K11)

Three fins: TSK T-7 is thinner

Angled part of the tail fins: Shape is different

Inner volume of afterbody:
TSK T-7 is smaller by about 5 cm³.
Structural differences between LMS T-7 and TSK T-7 (more with afterbody)

Water pass (four holes around the central rod):
- TSK T-7 is smaller

Four protuberances: exists only in LMS’s probes
Rough summary of the probes tested (only for weight)

The weight differences between LMS and TSK T7 is rounded to 10g. The structural differences are dismissed here.

<table>
<thead>
<tr>
<th></th>
<th>TSK(NML)</th>
<th>TSK (-10g)</th>
<th>TSK (-20g)</th>
<th>LMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>nose</td>
<td>–</td>
<td>10g lighter</td>
<td>20g lighter</td>
<td>same</td>
</tr>
<tr>
<td>surface</td>
<td>–</td>
<td>same</td>
<td>same</td>
<td>10g lighter</td>
</tr>
<tr>
<td>wire</td>
<td>–</td>
<td>same</td>
<td>same</td>
<td>10g lighter</td>
</tr>
<tr>
<td>total</td>
<td>–</td>
<td>10g lighter</td>
<td>20g lighter</td>
<td>10g lighter</td>
</tr>
</tbody>
</table>

Compared to TSK(NML)

<table>
<thead>
<tr>
<th></th>
<th>TSK(NML)</th>
<th>TSK (-10g)</th>
<th>TSK (-20g)</th>
<th>LMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>nose</td>
<td>–</td>
<td>10g lighter</td>
<td>20g lighter</td>
<td>same</td>
</tr>
<tr>
<td>wire</td>
<td>–</td>
<td>same</td>
<td>same</td>
<td>10g lighter</td>
</tr>
<tr>
<td>total</td>
<td>–</td>
<td>10g lighter</td>
<td>20g lighter</td>
<td>same</td>
</tr>
</tbody>
</table>

at rated depth+

<table>
<thead>
<tr>
<th></th>
<th>TSK(NML)</th>
<th>TSK (-10g)</th>
<th>TSK (-20g)</th>
<th>LMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>nose</td>
<td>–</td>
<td>10g lighter</td>
<td>20g lighter</td>
<td>same</td>
</tr>
<tr>
<td>wire</td>
<td>–</td>
<td>same</td>
<td>same</td>
<td>10g lighter</td>
</tr>
<tr>
<td>total</td>
<td>–</td>
<td>10g lighter</td>
<td>20g lighter</td>
<td>same</td>
</tr>
</tbody>
</table>
The test

Conducted during Feb 27-Mar 6 2011, south-southeast of Japan, as a part of KH11-3 cruise (Feb.25-Mar.10) of R/V Hakuho Maru (JAMSTEC).

Two or three dozens for each of normal TSK T7, 10g-reduced TSK T7, 20g-reduced TSK T7, and normal LMS T7 were deployed during CTD observations.

Two launching/acquisition systems were used in parallel in most cases.
- To minimize the time difference, and
- To test many probes in limited ship time.

A regularly-calibrated CTD (Sea-Bird Electronics SBE-9) was used as a truth.
Number of probes tested

<table>
<thead>
<tr>
<th>System #1</th>
<th>TSK</th>
<th>-10g</th>
<th>-20g</th>
<th>LMS</th>
<th>Total tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSK</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>-10g</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td>-20g</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>LMS</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>22</td>
</tr>
</tbody>
</table>

- TSK’s handheld launcher and MK-130 were used in either systems.
- All XBT’s were deployed during CTD measurements.

Number of profiles with good depth coverage:

TSK(normal): 23, TSK(-10g): 32, TSK(-20g): 32, LMS: 19
Temperature profiles at the test sites

Most profiles are obtained from areas with relatively high subsurface temperature.
Error of XBT depth is estimated by the method of Hanawa and Yasuda (1992).

1) Assume CTD temperature profile as truth.

2) Find $\Delta z$ that gives the minimum of

$$\int_{z+\Delta z-dz}^{z+\Delta z+dz} \left( \frac{dT}{dz}_{XBT} - \frac{dT}{dz}_{CTD} \right) dz$$

for each depth.

3) $\Delta z(z)$ gives the depth error profile for that probe.

*) Resistive to errors in temperature.

*) Does not work well in areas with weak thermal stratification.
Depth error of H95 for each type

**LMS:** Depth error is positive. True fall rate is <2% smaller than H95.

**TSK:** Depth error is negative. True fall rate is 2% greater than H95.
Our previous test (May 2008; East of Japan; K11)

Sippican: Depth error is positive. True fall rate is >2% smaller than H95.

TSK: Depth error is negative. True fall rate is <2% greater than H95.
Depth error of H95 for each type

Fall-rate (depth averaged): TSK > TSK(-10g) > TSK (-20g) > LMS
Obtained FR coefficients

\[ z(t) = at - bt^2 \]

Faster fall

Slower fall

\[ K11 \text{ (TSK)} \]

\[ K11 \text{ (LMS)} \]

\[ H95 \]

\[ Sippican \]

H95: Hanawa et al. (1995)
K11: Kizu et al. (2011)
Initially weigh the same

Common wire
Obtained fall-rate coefficients (summary)

<table>
<thead>
<tr>
<th></th>
<th>This study</th>
<th>K11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b × 10³</td>
</tr>
<tr>
<td>TSK</td>
<td>6.877 ± 0.114</td>
<td>2.78 ± 1.36</td>
</tr>
<tr>
<td>TSK (-10g)</td>
<td>6.739 ± 0.100</td>
<td>2.51 ± 1.06</td>
</tr>
<tr>
<td>TSK (-20g)</td>
<td>6.721 ± 0.123</td>
<td>2.70 ± 1.36</td>
</tr>
<tr>
<td>LMS</td>
<td>6.570 ± 0.130</td>
<td>1.81 ± 1.23</td>
</tr>
</tbody>
</table>

- The coefficients obtained are similar to those by K11.
- The b coefficients of the three TSK subtypes are similar (c.f. common wire).
- LMS T7 falls systematically more slowly than 20g-reduced TSK T7. (The former is heavier than the latter by about 10g initially, and by about 20g when the probe wire is expired.)
- The effect of weight is not proportional. The fall-rate difference between 10g-reduced TSK T7 and 20g-reduced TSK T7 is smaller than that between normal TSK T-7 and 10g-reduced TSK T7.

The effect of weight difference is minor (the actual manufacturers’ weight tolerance is much smaller than this!). It doesn’t explain the systematic difference in fall rates between LMS T7 and TSK T7.
Some samples from paired tests

**TSK(NML) vs. LMS**

**TSK(-10g) vs. LMS**

**Gray: CTD**
Some samples from paired tests

TSK(NML) vs. TSK(-10g)

TSK(NML) vs. TSK(-20g)
Some samples from paired tests

**TSK(-10g) vs. TSK(-20g)**

Gray: CTD
Some samples from paired tests

Almost indiscernible, but heavier one fell more slowly.

Almost no depth difference, rather there is temperature bias.
Initial fall-rate does not simply reflect difference in probe weight. Large scatter among cases.

Initial fall-rate ("a" coefficient)

Weight: -20g < LMS ≈ -10g < TSK

TSK-LMS difference at the rated depth is smaller than the initial one, but still exists.
Change of fall-rate during fall

\[ \text{Wratio} \equiv \frac{\text{probe weight without wire}}{\text{total probe weight}} \]

Final weight

Initial weight

Probes doesn’t slow down as much as their weight decreases during fall.

Water drag reduces as the weight balance changes by sending wire out?

Histogram of \( V(760m) / V(\text{initial}) \)

**TSK (normal)**

\[ \text{Wratio} \approx 0.84 \]

**LMS**

\[ \text{Wratio} \approx 0.86 \]
Scatter is substantially reduced by depth correction.

Reduction of mean error is not impressive.

Positive error remains in both cases.
Some samples from paired tests

Suggesting wire problem, but no appreciable spikes are identified in either cases. (these are almost raw data)
Conclusions

- Compared to H95, recent TSK T7 falls more quickly and recent LMS T7 falls more slowly. The relative difference between their depth biases is 3-4% (the results of K11 is confirmed).

- Impact of weight reduction (by 10g/20g) is appreciable, but it is still too small to explain the fall-rate difference between TSK T7 and LMS T7.

- The manufacturers’ weight tolerance (±1g/±5g) is probably good enough to control the fall-rate of T7 within <1%.

- Impact of weight reduction is not proportional to the weight difference, indicating that factors other than total weight (maybe structure) is important.

- Large scatter is in every group. It suggests that environmental factors (i.e. waves, ship motion, probe’s attitude at water entry, turbulence, etc.) can modify the fall-rate in invincible way. This can also spoil at-sea-type tests with small sample size (like ours!).
Still, the biggest question is,

**From when, and how did they change?**

- Both the manufacturers claim, “we did not make any change, particularly in a manner that the fall-rate is affected”. If so, why is there sizable difference in the fall-rate of recent probes that was not found by H95?

- Is it just a batch-to-batch difference? Our sample may be too small to deny this possibility, but 3.5% is quite large.

- The weight of probes has been controlled by both the manufacturers. But, how about structure?
Thank you.

Shoichi Kizu
kizu@pol.gp.tohoku.ac.jp
Earthquake on March 11, 2011 (Mw=9.0)

Sendai Station

Sendai Airport

Where I live

Our campus

Flooded area (near Sendai)

Sendai Airport

4km
Sendai (where we live)
Tokyo
Miyagi Pref.
Japan Sea
Japan-Hawaii Monitoring Program
PX-40
Tokyo
Sendai (where we live)
Fukushima Nuclear Power Plants
Japan Sea
Pacific Ocean
Fukushima
Nuclear Power Plants
Port changed since 2008
(Misaki near Tokyo
>>> Ishinomaki
or Kesennuma)
Kesennuma
Ishinomaki
where the schools are
were
Hawaii
3 transects per year
JAHMP XBT/XCTD Positions
Oct., 1998 - Mar., 2010
Coastal area sank by up to 1.2m.
Many towns are still without recovery of drainage.
Frequent aftershocks

Size of circles: JMA scale (similar to Richter’s scale) of the aftershocks

Color: Depth of their centers

March 15 – April 14 (30 days)  June 8 – July 8 (30 days)
In Fukushima 1st Plant, there’re 6 of total 54 reactors in Japan (incl. out of operation).

Most of Japan (incl. Sendai) is believed to be safe, but some parts of Fukushima Pref. are not. We’re also worrying about power shortage expected nationwide in this summer due to suspension/failure of many power plants (both nuclear and thermal) as a direct/indirect consequence of the earthquake/tsunami.

The nuclear power plants

![Map of Fukushima Pref.](image)

Miyagi Pref. (our pref.)

Fukushima Pref.

Fukushima 1st Nuclear Power Plant

Outside air

On soil ground (near surface)

▲ Measurement near our campus (mSv/h)

▼ Estimated integral dose (mSv) in one year after the accident (by TEPCO; Apr., 26, 2011)