“The difference with LNG? It’s just about boil-off isn’t it?”

The title to this paper reflects the sweeping generalisation often encountered when LNG chartering is mentioned amongst those more familiar with other tanker trades.

The paper deals with how the charterer holds the owner accountable for the energy available through the vapourisation (boil-off) of an LNG cargo, why certain approaches have been adopted in LNG chartering, and why some, on the face of it logical alternative approaches, have not.

the basics

Liquefying natural gas reduces it volume by a factor of over six-hundred times; an obvious advantage for transportation by sea. However, whilst storing LNG in pressurised containment systems (i.e. type ‘C’ cargo tanks) would minimise the prospect of vapourisation (and thus cargo loss), this is not practical for the scale required in a conventional LNG carrier.

Instead, LNG is transported in cargo tanks designed for near atmospheric pressure condition and which are insulated to minimise heat in-leak[1] (the relief valve set pressure is usually only around 250-350 mbar and normal operating pressure is around 80-120 mbar)[2].

As the insulation cannot prevent heat in-leak, vapourisation of the LNG is an unavoidable consequence. As the LNG vapourises, the pressure within the cargo tanks has to be relieved, to avoid endangering the integrity of the containment system. However, maintaining a constant vapour pressure within the cargo tanks also assists in maintaining the liquid temperature of the LNG - because of a property known as auto-refrigeration, whereby the vapourisation draws heat away from the liquid.

Therefore, provided that the cargo tanks are sufficiently insulated and the vapour pressure in the cargo tanks is managed, LNG can be carried economically with comparatively minimal loss of cargo through vapourisation (‘natural’ boil-off).

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[1] Note that this is in contrast to LPG carriers, which are often designed to carry cargoes in fully or semi-pressurised condition.

[2] These tank types are referred to in the IGC Code as Type ‘A’ or ‘B’.

'natural' boil-off

When at sea[3], a conventional LNG carrier uses low duty compressors to take the boil-off vapour from the headers of the cargo tanks (in balance to the rate of boil-off: so as to maintain a constant vapour pressure).

The boil-off is then taken either (i) via a heater[4] to the engine room for use as fuel for the LNG carrier's power or propulsion plant (thus reducing dependency on fuel oil[5]); or (ii) to a re-liquefaction plant (if so equipped), from which it can be returned to the cargo tanks as LNG.

Alternatively, when the LNG carrier is alongside an export (liquefaction) or import (regasification) terminal, a vapour return line is connected between the cargo tank headers of the LNG carrier and the terminal's[6] storage tanks, to avoid the need for venting and to maintain optimal conditions for efficient cargo transfer.

Additionally, it is a standard safety feature of LNG carriers, to protect the cargo tanks from over-pressurisation (or indeed vacuum), is the fitting of a common relief valve and pairs of relief valves for each cargo tank (venting through masts on deck). However, as venting to the atmosphere is strictly controlled, this is usually the last resort (necessitated by plant failure or inundation). Further, it is any event wasteful to release, as boil-off, what is a valuable cargo.

Where the volume of vapours cannot be utilised in these ways, it may be disposed of (flared) in a gas combustion unit (GCU).

Those LNG carriers that were fitted with steam-turbine plants may also be able to dump steam from their boilers to a condenser, thus allowing additional boil-off to be consumed (by increasing the steam load).

To put all this in context, the later dual-fuel diesel-electric (DFDE) propelled LNG carriers (which are much more efficient than steam plant) are generally able to achieve around 16 knots through the water, in fair conditions, whilst consuming only 'natural' boil-off (and some 'pilot' fuel oil[7]).

It is also worth noting that there are a significant number of LNG carriers (all of the Q-Flex and Q-Max vessels) that were designed without the ability to consume boil-off as fuel (they were equipped with slow-speed diesel engines[8]). Instead they were built with re-liquefaction plant as their primary means of addressing boil-off, although the fuel consumption in operating this plant (which has a capacity to handle around 5,500 m^3 of boiled-off gas per hour) has reportedly proved to be about 30mt[9] of fuel oil per day and even then the plant may not be fully (i.e. 100%) effective in preventing cargo loss[10] through boil-off[11].

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[3] If not ordered to 'force' boil-off – as explained later (below)

[4] The low duty heater is used to raise the temperature of the boil-off vapours to the design temperature (about +30°C) for burning in the LNG carrier's plant. The LNG carrier will also have high duty heaters for purging the cargo tanks prior to gas-freeing.

[5] Although designed to burn boil-off along with 'pilot' fuel oil in the boilers, even the first purpose built LNG carrier ("METHANE PRINCESS") was able to operate on boil-off only.

[6] Usually there is one dedicated chiksan (hard-arm) connection for vapour return.

[7] Although note that there are Rolls Royce Kvaernar engines in operation (on LNG as marine fuel ships) that require no pilot fuel.

[8] In isolated preference to the, then prevalent, steam turbine and, soon to be prevalent, DFDE designs.

[9] For a Q-Flex

[10] Noting that there is no economic benefit to operating a fully effective re-liquefaction plant, as the LNG is traded by energy.

‘natural’ boil-off rate

The rate of ‘natural’ boil-off for any given LNG carrier is primarily determined by the extent and effectiveness of its cargo tanks’ insulation. Assuming that the integrity of the insulation is maintained, this factor should remain constant, during the LNG carrier’s life.

A variable factor, which will affect the rate of ‘natural’ boil-off, will be the environmental conditions encountered. For example, when an LNG carrier encounters adverse sea conditions, the LNG may come into contact with the warmer upper-most surfaces of the cargo tanks and its surface area will be extended as it sloshes within the cargo tanks. As a consequence, the rate of ‘natural’ boil-off (BOR) may increase.

As indicated above, the BOR is also affected by variation in the pressure of the LNG within each cargo tank; hence why the pressure of the LNG has to be carefully controlled, by adjusting the volume of vapour removed from the headers of the cargo tanks[12].

The BOR warranties given by shipyards (and hence from the owners of LNG carriers to their charterers) have significantly reduced over recent years as increasingly more effective insulation is adopted on newer buildings. The latest laden warranties for BOR are around 0.075%[13], compared to the more usual 0.125% of even five or so years back; an improvement that equates to a significant reduction in freight costs. All the more so, when compared to some of the older LNG carriers in operation, where 0.15% or even 0.17% is more usual[14].

However, whereas the shipyard’s BOR warranty is usually limited to when the cargo tanks are in laden condition, it is customary (see ‘Form B’ para. 8(i) of the ShellLNGTime1 form) for the owner also to warrant the BOR for ballast condition.

This may seem illogical, particularly if only unpumpable quantities of cargo remain on board. However, if, as is the norm, the LNG carrier is required to arrive at the next loadport in ready-to-load condition, then some cargo will usually be retained (as ‘heel’) in order to ensure that the tanks can be maintained in cool condition and with sufficient quantity of LNG (after taking account of boil-off during the ballast passage) to be able to cool down the LNG carrier’s cargo lines and the terminal’s loading arms. Further, depending upon the comparative values of LNG and fuel oil, it may make sound economic sense for a charterer to retain sufficient heel onboard to avoid, or minimise, reliance on consuming fuel oil for the ballast passage[15]. Particularly in trades where the LNG carrier would otherwise need to deviate from her direct passage to stem bunkers.

The absence of any BOR warranty from the ship yard, when in heel condition, might be seem to present an argument against the owner warranting the same to a charterer (at least before experience of the LNG carrier’s performance is gained). However, unsurprisingly, the charterer

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Therefore, the additional energy (fuel oil) needed to re-liquefy the small nitrogen component (as it has a lower boiling point than methane) would be wasted (even as against the costs of Wobbe correction at the discharge port, if the LNG was traded on FOB basis). In disregarding the nitrogen (and thus full effectiveness of the plant), inevitably some methane sacrifice is made.

[11] Although the conversion of these engines to be able to utilise boil-off (ME-GI design) is under advanced consideration at time of writing.

[12] The temperature of the LNG also affects the rate of BOR, however, there is little that can be done to control the temperature of the LNG onboard.

[13] In particular for Sayendo and latest Moss type containment systems

[14] In economic terms, the difference is more stark when the energy efficiency of the steam plants on these older LNG carriers is compared to the DFDE (or even tri-fuel) plants on their modern counterparts.

[15] This may be particularly so in the context of LNG carriers serving older projects, with lower US$/MMBtu values for LNG.

will expect some parameter with respect to boil-off on the ballast voyage to ensure that the requirements for arrival condition at the next load port can be met while at the same time maximising the out-turn of the cargo.

Typically, the same BOR is warranted for both laden and ballast conditions. If so, this should provide a comfortable margin for an owner, as, where a distinction is made, the BOR warranty for heel condition is usually lower (although rarely close to the half-rate that experience might support[16]).

However, it is worth noting that, in response to the trend for re-loading cargoes (e.g. out of Spain and, before this, the US) for export, some owners have limited their BOR warranties to a range of cargo temperatures, so as to distinguish the warmer temperature of re-load cargoes (where the actual BOR would be correspondingly higher).

'natural' boil-off performance

For the purpose of analysing the LNG carrier's performance, the loss of LNG to boil-off is usually assessed by volume lost between gauging (conducted whilst alongside, both before and after the sea passage). The volume lost is then compared against the owner's warranted performance of the cargo containment system (i.e. the BOR) for the period between these gauging[17].

However, whilst this is the approach commonly adopted, it should be noted that any change in the bulk liquid temperature of the LNG (between the gauging) will distort the result. A true assessment of the boil-off would require any change in temperature to be accounted for.

Additionally, the inaccuracy of volumetric measurements should be recognised. GIIGNL estimates[18] this at about + or - 0.21%, which for a 150,000 m^3 LNG carrier equates to + or – 315 m^3.

The owner's warranty is usually expressed as a percentage of the total volume of LNG that the cargo tanks are permitted to carry[19] (about 98.5% of the total tank capacity, depending on the type of containment system), per day or *pro rata*.

By contrast, the warranties given by shipyards are usually expressed as a percentage of the total volume of the cargo tanks and not what they are permitted to carry. Therefore, simply transcribing the percentage (between a building contract and a charter party) may not achieve a back-to-back warranty. Rather, it will be disadvantageous[20] for the owner, vis-à-vis the charterer, albeit the difference should be within the (safe) margin that the builder would have included in its warranty.

Within this warranted limit, the charterer permits the owner to consume the boil-off as fuel for the LNG carrier and will expect a corresponding saving on fuel oil. That is, unless the charterer has given orders for the re-liquefaction plant (if fitted) to be utilised.

In addition to the primary warranty, a secondary warranty is usually provided if not all the cargo tanks were used on the laden passages[21] (which is still a rare circumstance). The ShellLNGTime1

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[16] It is more common to see a provision reducing warranted BOR rate where heel is consolidated into one or two cargo tanks

[17] Any periods during which the LNG carrier is off-hire are usually excluded though and addressed separately

[18] See the 'Custody Transfer Handbook' (3rd Edition) published by GIIGNL

[19] For example, see Clause 26(g) and (h) of ShellLNGTime1 and the definition of "*Cargo Capacity*" as this "*means the maximum safe LNG loading limit of the Vessel as per Appendix A*" (which means to refer to 8(b) of the same)

[20] By 1.5% under ShellLNGTime1 (the difference between 98.5% and 100%)

[21] For example, see the mechanism in Clause 26(g) and (h) of ShellLNGTime1

form reduces the primary warranty *pro rata* to the number of cargo tanks used, not to the comparative capacity available in the tanks in use (noting that the forward cargo tank is usually of lesser capacity). However, an alternative provision (more common in long-term charters) is to provide a pro-rata approach based on the ratio of the volume of the cargo loaded to the cargo capacity of all the cargo tanks.

The same secondary warranty applies on the ballast passages, although often any heel may be consolidated into one cargo tank (to minimise the loss of heel through boil-off[22]) and the unpumpables remaining in other cargo tanks would be expected to boil-off in fairly short order. As such the secondary warranty should provide a considerable comfort margin to the owner on such ballast passages. However, the benefit of the boil-off, for consumption as fuel, will still be assessed (within the performance of the LNG carrier).

Notably, whereas (as discussed above) the environmental conditions encountered will affect the rate of ‘natural’ boil-off, there is customarily no exclusion for when the LNG carrier encounters adverse conditions (i.e. equivalent to non ‘good weather’ days in relation to speed and performance warranties). The BOR warranties are expected to provide sufficient comfort margin to address such encounters.

‘forced’ boil-off

If ‘natural’ boil-off is insufficient to meet the fuel consumption needs of the LNG carrier at the required sea speed, ‘forced’ boil-off can be used as a supplement to remove or minimise reliance on fuel oil.

This process is performed by taking LNG (as liquid not vapour) from a cargo tank (by way of the stripping or spray pump system) and passing it through forcing vapourisers until it emerges as vapour at the same temperature (about -40°c) as the ‘natural’ boil-off taken from the cargo tank headers.

If a charterer requests the owner to force boil-off on passage, to avoid (or minimise) reliance upon fuel oil consumption, then the BOR warranty must be waived[23], although (again) the benefit of its consumption, as fuel, will still be assessed (within the performance of the LNG carrier).

Similarly, if spray cooling is required during a ballast passage (e.g. to ensure that the LNG carrier arrives with her cargo tanks in ready to load condition), the BOR is usually waived from that point in time until the end of the passage.

The energy value of ‘natural’ and ‘forced’ boil-off

The composition of LNG shipped onboard LNG carriers varies depending on its source. However, the main component is always methane, which condenses (liquefies) beneath -161°C[24]. As this temperature is considerably lower than that at which the other (heavier) hydrocarbon components (e.g. ethane, propane and butane) of LNG condense, it means that methane is the first such hydrocarbon component to vapourise (through ‘natural’ boil-off) as the LNG absorbs heat.

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[22] On longer routes this might produce a saving of around 1,000 m^3 over the ballast passage, although in turn this may require the consumption of fuel oil to make-up for the reduced volume of boil-off gas available as fuel.

[23] The ShellLNGTime1form (see Appendix C Article 7(b)) deems the warranty complied with if the charterer gives orders “*that require the temperature or vapour pressure of a cargo to fall during a laden sea passage and that order is complied with...*”

[24] The atmospheric boiling point of methane.

However, within the composition of an LNG cargo (aside from the hydrocarbons[25]) there is usually a small percentage of inert gas, such as nitrogen. Nitrogen will preferentially boil-off, as compared to the methane component, as its atmospheric boiling point is -196°c. Therefore the energy value of 'natural' boil-off vapours should increase over time (e.g. a sea passage), as the nitrogen component is depleted.

However, as the temperature of the LNG cargo should (under normal carriage conditions) only rise slightly above the temperature at which methane condenses, none of the other hydrocarbon components of LNG should vapourise. Therefore, for the purposes of 'natural' boil-off on laden passages, there is no reason to make any distinction between 'rich' or 'lean' LNG cargoes[26].

The contrary is true, in terms of 'forced' boil-off, as there is a difference in the energy (calorific value) available to the owner from such variants (between 'rich' and 'lean' cargoes).

Further, for ballast passages, once the methane component in the heel is consumed through boil-off, the remnants of the heel will be the heavier hydrocarbon components (e.g. butane, propane and ethane), as these have a higher boiling point. These heavier components are also richer (in calorific terms) than the methane component and thus (strictly) it does make a difference whether the heel (usually the preceding cargo) was 'rich' or 'lean'[27].

Fuel oil equivalent factor

The 'Fuel Oil Equivalent Factor' is a contractual means of converting a volume (m^3) of LNG to its equivalent mass (mt) in fuel oil. The primary need for this is so that the charterer can assess whether it has obtained the equivalent value of the boil-off ('natural' or 'forced') when assessing whether the owner has met its speed and consumption warranties.

The ShellLNGTime1 form promotes[28] the agreement of a fixed conversion factor and makes no distinction between 'natural' or 'forced' boil-off[29], notwithstanding that the latter is more energy rich than the 'natural' boil-off.

The most widely adopted 'Fuel Oil Equivalent Factor' appears to remain as 1 m^3 of LNG being equal to 0.48 (or perhaps 0.484) mt of fuel oil. By any measure, it should not be controversial to suggest that the use of this figure favours the owner (when consuming boil-off as fuel).

If we ignore the nitrogen content and assume that only pure methane will boil-off, the calorific value of the boil-off would be about 50MJ/kg[30], whereas, the calorific value of IFO380 is about 40MJ/kg. At -160°C, the density of methane is about 420kg/m^3. Therefore, each cubic metre of boil-off is equivalent to around 0.525 mt of IFO380[31].

By comparison, MGO and MDO have a calorific value of around 42.75MJ/kg. With the same assumptions with respect to the boil-off applied, the same calculation would result in each cubic metre of boil-off being equivalent to around 0.49 mt of MGO.

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[25] All of which are within the alkane group.

[26] The difference being the proportion of methane as compared to the other hydrocarbons components of the LNG.

[27] Further, in the context of steamship LNG carriers, once the composition of the heel becomes dominated by the heavier hydro-carbon components, the boilers may struggle to operate on boil-off gas alone, requiring the use of fuel-oil to maintain ignition.

[28] See Clause 26(f)

[29] See Clause 50 – Definition of 'Boil-Off' as "*vapour, which results from vaporisation of LNG in the cargo tanks*".

[30] Using the Lower Heating Value for methane.

[31] Hence why 0.525 is the most common alternative to 0.48(4).

Accordingly, it can be seen that a 'Fuel Oil Equivalent Factor'of 0.48(4), assumes that the alternative to boil-off is MGO or MDO, whereas, for the most part, the appropriate comparison would be to IFO.

However, whilst it is convenient to ignore the nitrogen content, the reality is that most commercial grades of LNG have a small quantity[32] of nitrogen in the liquid phase. Since the atmospheric boiling point of liquid nitrogen is some 35°C below that of methane, it boils off preferentially. It can therefore be prevalent in the vapour phase, and be a practical source of inaccuracy to the above theoretical assessment of what the equivalent use of fuel oil might be[33].

The other main practical hindrance to an accurate assessment of the equivalent use of fuel oil is that the bulk liquid temperature of the LNG may change on passage (as noted above). Indeed, it is common for there to be a slight increase in temperature and therefore a corresponding increase in the liquid volume.

Notably, the two would usually have contrary influences. However, the former presents the least hindrance to accuracy, as the bulk liquid temperature change can be determined and the effect can be accurately calculated. By contrast, the available gas chromatograph composition analyses of the LNG will not be sufficient to determine with accuracy the influence of the nitrogen component upon the assessment of the equivalent use of fuel oil.

It is more difficult to address, in the abstract, the 'forced' boil-off, given the multitude (and greater magnitude[34]) of variables between cargoes depending on origin and market. For specific cargoes, a fair compromise might be to adopt a mean of the LNG compositional analysis at the loading and discharge ports. However, what can be safely assumed is that 'forced' boil-off will have a (slightly) higher calorific value and density than 'natural' boil-off.

In conclusion, it seems fair to suggest that where 'natural' boil-off is utilised in lieu of (IFO) fuel oil, then a 'Fuel Oil Equivalent Factor' of 0.48(4) essentially provides the owner with an 8% margin on fuel performance, more so where 'forced' boil-off is utilised.

Although the ShellLNGTime1 form promotes the use of a fixed 'Fuel Oil Equivalent Factor', the provision is sometimes amended so that a representative 'Fuel Oil Equivalent Factor' is to be calculated, for each passage (laden or ballast).

Where this amendment is made, the calculations are usually reliant on the bunkers analysis reports (from sampling at each stem). As it has become customary, in recent years, to analyse the calorific value of bunkers, rather than mere ISO compliance (the criteria of which did not necessarily ensure that a fuel was fit for purpose), the necessary analysis will usually have been obtained and thus be available as a matter of course.

Logically, this approach to determining the fuel oil equivalent might be extended to include an assessment of the calorific value of the 'boil-off' (without being able to make a distinction between 'forced' and 'natural' boil-off) by reference to the LNG compositional analysis. Indeed, the logical conclusion (of this approach) would be that the boil-off used on (laden) passage should be derived

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[32] From most origins the content is less than 0.2%, rising up to around 0.7% for LNG from Algeria.

[33] A nitrogen content of 0.2% would equate to almost 300m^3 of a 150,000m^3 cargo of LNG and due, to its preferential boil-off over methane, the resultant inaccuracy would be more acute on shorter passages.

[34] Noting that the methane component (and therefore other alkane components) of commercial grades of LNG varies by up to 17% between origins.

from the difference in the total heating value of the cargo on departure from the loading port and on arrival at the discharge port.

Such an approach certainly appears to be more consistent with how LNG is traded (in MMBTU, not volume) and, as compared to the fixed bias of a 0.48(4) 'Fuel Oil Equivalent Factor', ostensibly should be more favourable to the charterer. However, the margins of accuracy required of and achieved by the Custody Transfer System (CTS) measurements create a practical barrier to such extended logic.

The overall degree of uncertainty in CTS measurements is about + or - 0.4%[35]. For the purposes of trading (and charging duty on) LNG this is accepted as being sufficiently accurate. However, for the purposes of assessing consumption the variances are simply too great.

To illustrate this point, for a 150,000 m^3 LNG carrier, this would equate to accepting a margin of error in a bunker survey of about + or – 300 mt of fuel oil; a margin of error that would apply at a bunker survey at both the loading and discharge ports. Essentially, the possible extent of the combined errors (600mt) could equate to around five days' worth of fuel oil consumption[36].

In any event, where a representative 'Fuel Oil Equivalent Factor' is to be calculated (at least by reference to bunker analyses), some thought has to be given with respect to referencing the bunkers analysis reports. As, save for a newly delivered LNG carrier, there may well be a mix of grades (e.g. IFO, MDO and low sulphur variants of the same) from different stems remaining on board, although, they should not be loaded on top (if good tank management is employed and sufficient bunker tanks allow).

Applying first-in / first-out principles to the use of each stem would, in most trades, offer some simplicity and fairness to both parties. However, if the LNG carrier is and has been operated so as to be largely reliant on boil-off for fuel for both laden and ballast passages, then fuel oil consumption may be minimal and the last stem might be somewhat more historic than in non-LNG trades. For this reason, a last-in / first-out approach may provide a more commercially manageable mechanism (as compared to the preponderance in other trades for a first-in / first-out approach).

However, for simplicity, it still seems that the preferred compromise might be to adopt a fixed (across the fuel grades and/or stems) but more representative energy value for the bunkers. Particularly as, with the current instrumentation system used in the LNG trade there is insufficient accuracy to hold an owner to account for the energy actually made available through boil-off.

In conclusion, whilst the simple method based on fuel-oil equivalency undoubtedly favours the owner (with generous margins), it is probably sufficient for most charter parties. That is provided there is a reasonable degree of trust between the parties, an assumption that may vary between the longer-term participants and those newer to the market and carriage of LNG by sea[37].

<u>LNG Price</u>

Naturally, whereas fuel oil is traded by mass, LNG is traded as energy (MMBTU) not volume and therefore, a conversion is required.

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[35] See the 'Custody Transfer Handbook' (3rd Edition) published by GIIGNL

[36] Assuming DFDE propulsion and an ordered speed in good weather of about 16 knots or so.

[37] Particularly, perhaps, where the *alma mater* of newer participants might be in the trade and carriage of oil cargoes.

The conversion from US$ per MMBTU to US$ per cubic metre of LNG (not vapour) is usually fixed, as the ShellLNGTime1 form promotes.

The most common approach has been to agree a flat rate during the charter, and in this respect the preferred rate appears to be about 23.0 MMBTU per cubic metre (the usual range being between 21 to 24 MMBTU per cubic metre).

However, in the alternative, the same could be indexed to the actual conversion figures in the last LNG analysis report (post loading or discharge).

For short-term or trip charters, a fixed 'LNG Price' is likely to be preferred, as timely availability of the figures may be an issue (although a default to a fixed conversion could be agreed). Whereas, in longer-term charters, the 'LNG Price' might well be averaged over and within the relevant annual performance period[38], based on the prices achieved under the charterers' (ex-ship) sale contract(s).

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[38] See Appendix C Article 8(f) within ShellLNGTime1 form.