

Evaluation of the uncertainty of the coefficient of thermal expansion of a ceramic dimensional gauge block measured by interferometry.

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Introduction

This project focuses on evaluating the standard uncertainty of the coefficient of thermal expansion of a ceramic dimensional gauge block using a Michelson interferometer. The precise knowledge of the physical properties of gauge blocks used as references in the calibration of dimensional magnitude measuring instruments is crucial for reliable measurement. Part of the project is the proposed design of the measurement system and the calculation of the best estimate to evaluate the uncertainty of the coefficient of thermal expansion.

Thermal Expansion Model

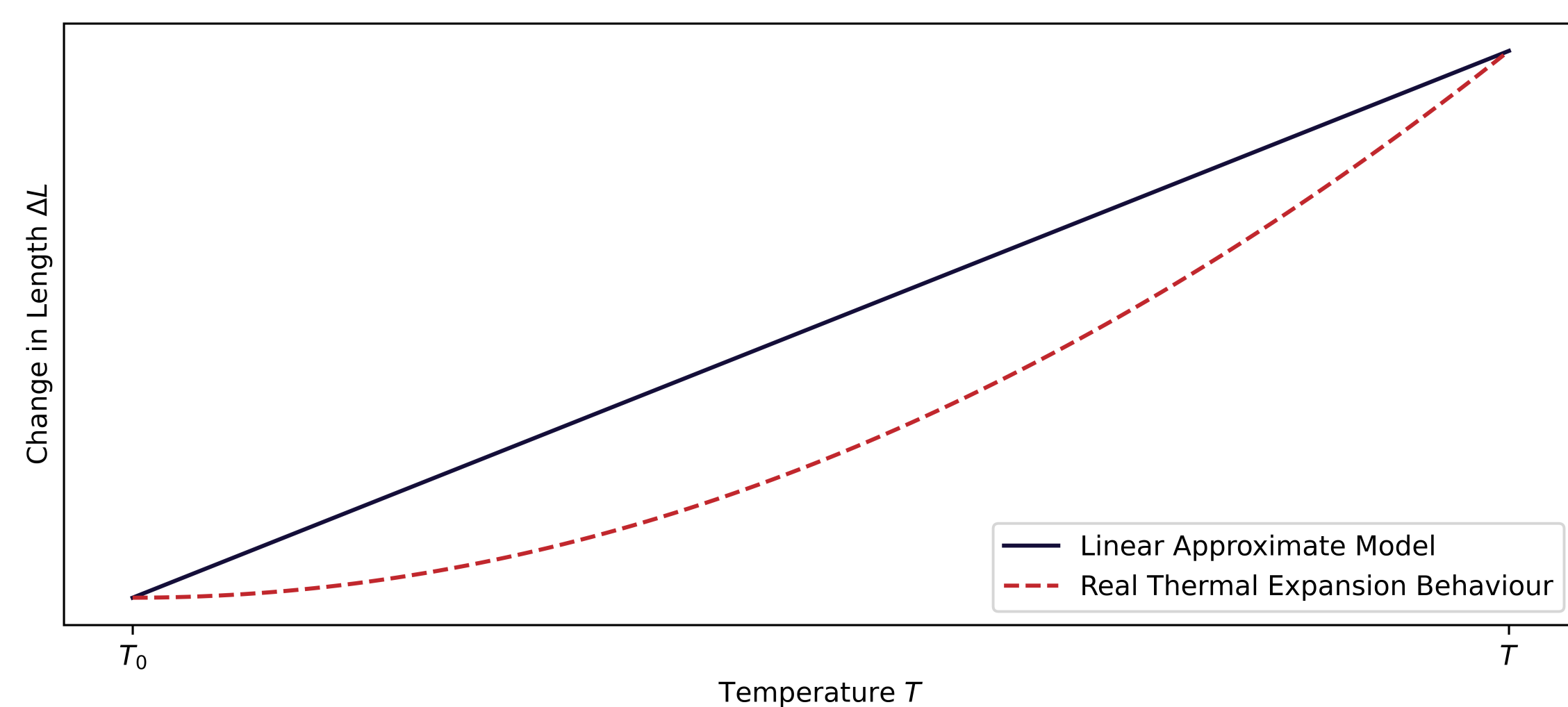


Figure 1. Model representation of the response of length of an object given a change in the temperature of the object.

By considering the thermal expansion of solids as a linear model when taking a defined difference in temperature, it is possible to determine the coefficient of expansion α as the rate of change of length when a change in temperature is applied to said solid.

Measurement Function

The coefficient of expansion can be expressed as

$$\alpha = \frac{N\lambda}{2L_0(T - T_0)}$$

where N is the number of transitions of the interference pattern, λ is the wavelength of the laser used in the method, L_0 represents the original length of the block at a temperature T_0 , and T is the temperature at which the count of transitions stops, or the final temperature.

Standard Combined Uncertainty

$$u(\alpha) = \left[\left(\frac{\alpha}{L_0} \cdot u(L_0) \right)^2 + \left(\frac{\alpha}{(T - T_0)} \cdot u(T) \right)^2 + \left(\frac{\alpha}{(T - T_0)} \cdot u(T_0) \right)^2 + \left(\frac{\alpha}{N} \cdot u(N) \right)^2 + \left(\frac{\alpha}{\lambda} \cdot u(\lambda) \right)^2 \right]^{1/2}$$

Uncertainty Weight Graph

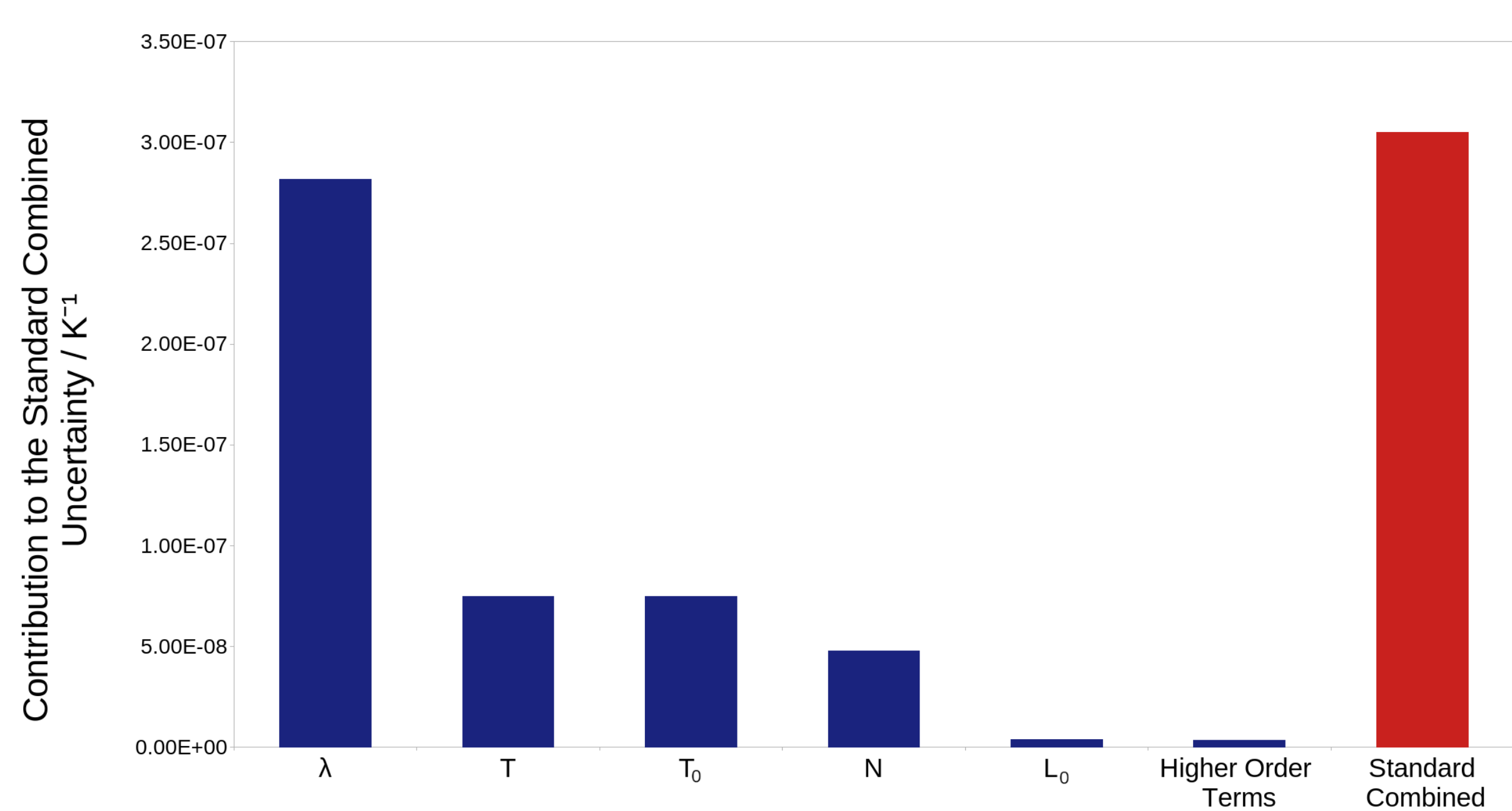


Figure 2. Weight Graph of Contributions to the Standard Combined Uncertainty of the Coefficient of Thermal Expansion

Provisional Uncertainty Budget

No.	Source of Uncertainty	Input Magnitude	Original Uncertainty	Type, Distribution	Contribution (°C ⁻¹)
1	Number of Transitions N	125	-	-	48,0 × 10 ⁻⁹
1a	Maximum N Error	-	± 1	B, Rectangular	48,0 × 10 ⁻⁹
2	Wavelength λ	532 nm	-	-	281,9 × 10 ⁻⁹
2a	Maximum λ Error	-	± 25 nm	B, Rectangular	281,9 × 10 ⁻⁹
3	Initial Length L ₀	80 mm	-	-	3,7 × 10 ⁻⁹
3a	Maximum L ₀ Error	-	± 0,05 mm	B, Rectangular	3,7 × 10 ⁻⁹
4	Object Temperature T	60 °C	-	-	75,0 × 10 ⁻⁹
4a	Maximum T Error	-	± 0,5 °C	B, Rectangular	75,0 × 10 ⁻⁹
5	Temperature of Reference T ₀	20 °C	-	-	75,0 × 10 ⁻⁹
5a	Maximum T ₀ Error	-	± 0,5 °C	B, Rectangular	75,0 × 10 ⁻⁹
-	Coefficient of Thermal Expansion	1,039 × 10 ⁻⁵ °C ⁻¹	-	Normal	u(α) = 305,1 × 10 ⁻⁹
Coefficient of thermal expansion (α) = (1,039 ± 0,062) × 10 ⁻⁵ °C ⁻¹ (k=2)					

Figure 3. Provisional Uncertainty Budget of the Coefficient of Thermal Expansion

Conclusions

When calculating the contribution of the first and superior order terms into the standard combined uncertainty, the results (Figure 2) show that only the first order terms are actually significant. Thus, the calculation of the standard combined uncertainty includes said terms only. The uncertainty regarding the wavelength is highly relevant, and so, the main focus relies on its later determination so the standard uncertainty can be reduced.

References

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