Method for Multi-Error Analysis and Simulation of Future Space Station Truss Application

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Challenges of Private sectors in Space

- The rise of private sectors in aerospace field
- Needs for building space station in a low effort
- Safety assessment and Uncertainty quantification
- The advance of private sectors into space station business
- Engineers should design space station considering the effort and safety

Figure1 Dragon spacecraft developed by SpaceX, a private sector in aerospace (JAXA/NASA)

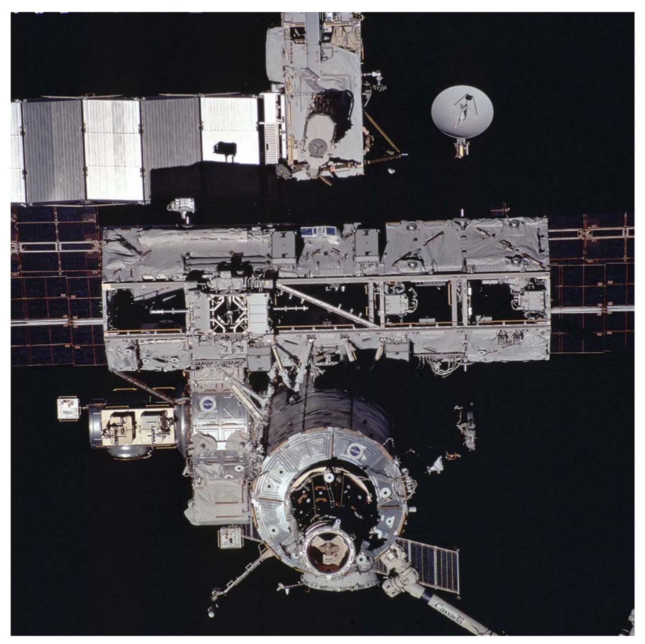

Figure2 ISS S0 truss (JAXA/NASA)

Presenting Novel perspective in Space

- To determine a truss structure which is tolerant in response to uncertain variation of rigidity due to low effort manufacturing effort
- To assess the safety of truss structure which contains slight difference in rigidity of each element
- To consolidate the method to evaluate safety and reliability of space truss structure which can be manufactured in low effort

Simulation Method

- This simulation used Monte Carlo Method
- Three types of truss   Each element is round bar
- Simulate the Young's modulus and diameter using Monte Carlo Simulation as the error from manufacturing and add the variance using random value within tolerance The value is voluntary
- Calculate the deflection of entire truss using Strain Energy and Castigliano's theorem

$$U = g(d,E) = \sum_1^k \frac{2F(P)^2}{\pi d^2 E} \quad \text{eq(1)} \qquad \Delta = \frac{\partial g}{\partial P} \quad \text{eq(2)}$$

P:load $F(P)$:member force d:diameter
E:Young's modulus k:elements U:Strain Energy Δ:deflection

- This process is repeated 10000times and approximate the probability density function to the distribution of deflection

Table1 Variables of rigidity

Diameter (d)	0.01 ± 0.0001 m
Young's modulus (E)	200 ± 1 GPa

Analytical Approximation

$$E[g(d,E)] = g(d_m,E_m) + \frac{1}{2}\frac{\partial^2 g(d_m,E_m)}{\partial d^2}\sigma_d^2 + \frac{1}{2}\frac{\partial^2 g(d_m,E_m)}{\partial E^2}\sigma_E^2 \quad \text{eq(3)}$$

$$V[g(d,E)] = g(d_m,E_m)^2 + \left\{\left(\frac{\partial g(d_m,E_m)}{\partial d}\right)^2 + g(d_m,E_m)\frac{\partial^2 g(d_m,E_m)}{\partial d^2}\right\}\sigma_d^2 + \left\{\left(\frac{\partial g(d_m,E_m)}{\partial E}\right)^2 + g(d_m,E_m)\frac{\partial^2 g(d_m,E_m)}{\partial E^2}\right\}\sigma_E^2 - E[g(d,E)]^2 \quad \text{eq(4)}$$

- To ensure that this simulation method is appropriate
- Calculate the analytical mean using Taylor expansion of $g(d,E)$

d_m:mean of diameter E_m:mean of Young's modulus
σ_d^2:variance of diameter σ_E^2:variance of Young's modulus

Simulation and Analysis Result

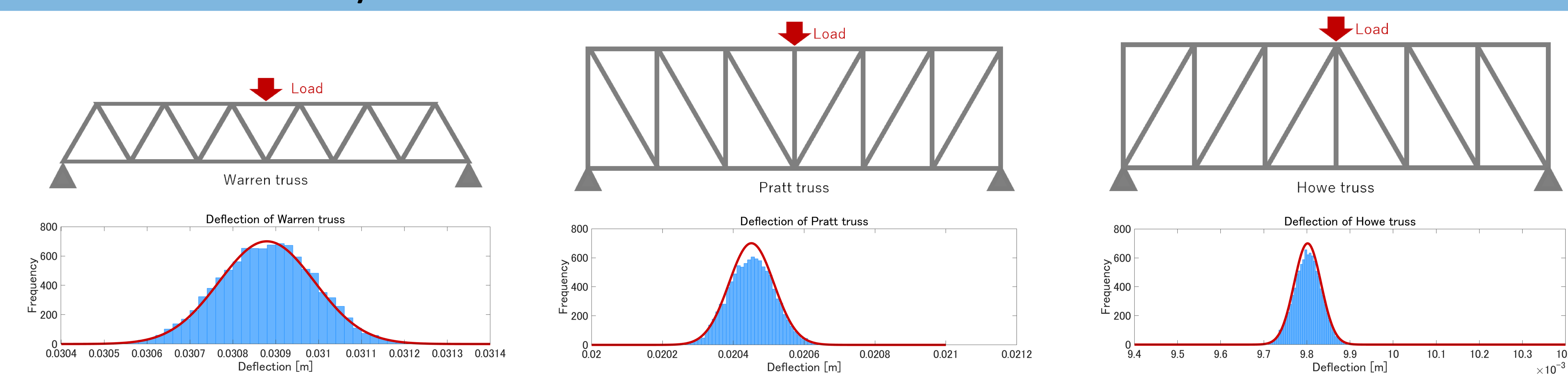

Figure3 three truss used in this research and histogram and probability density function of deflection

Table 2 mean and variance of simulation and analysis

	Warren		Pratt		Howe	
	m[m]	σ^2	m[m]	σ^2	m[m]	σ^2
Simulation	0.030879	1.24e-8	0.020451	4.02e-9	0.009802	9.73e-10
Analysis	0.030879	1.35e-7	0.020450	5.93e-8	0.009802	1.36e-8

Discussion and Conclusion

- All of the deflection can be fitted by Normal distribution
- Howe truss has the smallest value both in mean and variance This indicates that Howe truss is hard to bend and tolerant to errors compared to other two trusses
- Means from simulation and analysis are in good in agreement This indicates that this simulation method is reliable in consideration of the performance with slight difference in rigidity However, the variations are relatively big We need further analysis
- Considering the mean and variance might be effective in assessing the performance and reliability of product
- More consideration is needed in order to assess the reliability and performance in low manufacturing effort and encourage the movement of private sectors' space development and utilization in space technology

Path to more reliable space truss system

- Consider analysis method more for mean and variance
- Change the study target for different products and the error parameter
- Change the method to calculate the deflection or think other value to evaluate the performance
- Consider other way to assess the performance and reliability in low effort

Reference

- G Allegri, S Corradi, M Marchetti Stochastic analysis of the vibrations of an uncertain composite truss for space applications, (online), available fromhttps://www.sciencedirect.com/science/article/pii/S0266353805001478 (accessed 2018-09-09)

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