CAE Supported Sustainable Product Development - Case Study of Compact Flow Guiding with Flame Lift Mechanism

W L CHEN¹ and F L CHAO¹
¹Department of Industrial Design, Chaoyang University of Technology, Taichung, 436, Taiwan, R.O.C
E-mail: flin@cyut.edu.tw

Abstract. The flame device design process and lift mechanism concerns were investigated. Combine qualitative and CAE simulation were proposed to fulfill its functions. Redesign structures allow the user to add fuel and cleaning base parts safely. For enhancing usability, airflow guidance structure cannot tolerate interference with the fuel intake. Within space constrain, we changed guidance channel to produce an ornamental flame with acceptable flame height. The cover is movably engaged with the base and selectively closes the opening. The lift mechanism comprises a supporting member and bearing allow moving to the predetermined height. Rigid body linkage and flow field simulated enables fine tune of geometric design. Functional test and measurement are carried out to confirm the product features. The measured average temperature of the metal chassis is 37.25 °C and that of glass is 141°C. The result shows successful simplicity mechanism and low surface temperature design.

1. Introduction
For enhancing usability, airflow guidance structure needs producing an ornamental flame with acceptable flame height; and lift container vertically within space constrain. Sustainable design are assessed based on functional, economic, and ecological criteria to achieve sustainability [1], [2]. The checklist [3,4] support for the analysis of a product's impact on the environment to avoid missing significant features. The designers work out systematically of redesign tasks on parts, function and product levels. The main strategies are (1) selection of low-impact materials, (2) reduction of material usage, and (3) modification of production techniques, and (4) reduction of impact during use.

1.1. CAE in Sustainable design
The burning and heat transfer mechanisms caused the high temperature of body and parts. The primary target of flame module redesign is providing new structures that allow user can quickly perform the task without potential safety issues. Computational fluid dynamics (CFD) techniques are the foundation to predict airflow. Finite volume method is a conventional approach for large problems and source term dominated flows. Detailed calculation steps by CAE can support engineer to get right parameters. The abilities of prediction and insight of problem make CAE simulation important in sustainable design.

1.2. Qualitative guidelines
General design guidelines enable the designer to understand trend and major factors. The previous flow guidance design required large space and more material. To maintain production cost and reduce
raw material used, the size and shape of the airflow guiding channel need redesign to preserve ventilation path with minimum turbulence. The small size of guiding channel means lower natural convection flow caused by negative pressure.

High surface temperature causes user risk. From non-quantitative design guidelines, we can not only transfer the successful cases but also prevent possible pitfall that may happen. Those cases collected in different domains such as computer chassis, avionic facilities. Careful considering cases and guidelines will reduce risky design. The examples of the flow guidelines are as follows [5,6]:

- Air flow reversal may happen if inlet velocity is too high.
- Do not place the inlet of a blower directly downstream of the exhaust of another blower.
- Do not obstruct coolant flow, guide flow using splitters and turning vanes.
- Use gradual turns, enlargements, and contractions in flow passages.
- Install cooling fins vertically. Do not place parts directly above high dissipating elements.

Although some design guide prepared for electronic cooling, the fluid characteristic is the same with our combustion situation. For example, the effect of “Air flow reversal may happen, if inlet velocity is high” can be found in the real-world situation. As the velocity is increased, the static pressure will decrease. A high air velocity can result in such a low static pressure at the inlet [6]. When a flow reversal happens, the hot air will then be drawn in from the exit plenum. In Figure 1(d), a taper inlet channel is used so that the cross-section area at any point is higher than that of downstream. Without qualitative guidelines, usually, the CAE simulation gets no direction for selecting proper geometric parameters.

**Figure 1.** (a) Use gradual turns, enlargements, and contractions in flow passages; (b) Turning loss coefficients for fluids [5]; (c) Air flow reversal may happen if inlet velocity is high; (d) Improvement in the plenum design by taper channel [6].

1.3. Lift Mechanism
Redesign structures must allow the user to add fuel and cleaning base efficiently and safely. Mechanical CAE allows three-dimensional simulation of moving parts operating in conjunction with one another. Multibody dynamics get right parameters and prevent ill mechanism before prototyping. In [7], CAE was utilized to motivate student’s creativity in product design. Indications for evaluation provided first, and then students analyzes and classifies the proposed mechanisms. Authors found the importance of pre-defined evaluation criteria for benchmarking a high number of potential mechanisms. Students put a sketch of their solution in a common folder and shared directory concept with group members. Considering functional blocks, we can derive proper approach efficiently [7]. In [8], a scissor lift having upper and lower platforms and actuated by a cable reeved to pull at least one set of the ends of the scissor together at its extended position. It reeved a cam roller interposed between the arms and working toward the pivot connection. In [9], a lift system incorporates a transverse bar which carries a patient lift system for movement between two laterally extending bars. The transverse bar is mounted at the same vertical height as the laterally extending bars and carries a motor for lifting. In our design, evaluation criteria were set by the available benchmark. Fuel adding structures are chosen by designer. The CAE is then utilized to determine suitable parameters that fit pre-defined compact space.

2. Case study of flame redesign
For enhancing usability, airflow guidance structure cannot tolerate interference with the fuel intake areas. The design goals are within space constrain,
- changing guidance channel that producing an ornamental flame with acceptable flame height.
- choosing lift mechanism that can move vertically without skew to ensure liquid fuel will not spill out.

2.1. Design procedure
Biofuel which is low oxygen consumption is the fuel to producing an ornamental flame. First, the digital model were built using CATIA solid modeling package. Depending on the type of simulation (flow or mechanism), digital model was discretized into elements or mesh for setting up the system equation with boundary conditions. Static solutions of field distribution or time depended on the motion obtained by solving the linear matrix equations. The prototype model was built with the actual size and material so that engineer can measure corresponding physical parameters. The measured data are utilized to adjust the simulation parameters iteratively till results meet each other. When the simulation parameters are confirmed, digital model confidently presents a real system which reduces project developing cycle time.

![Figure 2. Design process](image-url)
As shown in figure 2, the design guideline help prevent mistake arrangements. CAD/ CAE are used to realize the idea quickly. The flow field or mechanism simulation enables fine-tuning before a series of measurements. After the design process, the checklist was reviewed to confirm the design.

2.2. Flow simulation results

In the case of the flame design, the complicated phenomena make CAE simulation much harder. Flow channel analysis was performed using non-premixed combustion mode. With the alcohol fuel combustion equation to make sure the amount of oxygen supply is sufficient.

\[ \text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O} \]  \hspace{1cm} (1)

In non-premixed combustion, fuel and oxidizer enter the reaction zone in distinct streams [10]. Under certain assumptions, the thermochemistry can be reduced to a single parameter: the mixture fraction. The mixture fraction is the mass fraction that originated from the fuel stream. The profiles of scalar properties provide an alternative thermochemical relationship to that of chemical equilibrium [9]. Velocity vector of XZ section (figure 3) indicates the oxygen supply is sufficient. The upwardly convection is on the outer edge of the cylinder. The overall flow line velocity diagram is helically raised. Table 1 suggests parameters based on simulation and measurement.

| Table 1. Analysis results of exhaust port velocity |
|--------------------------------------------------|
| Quantization value | entry value | Outlet value |
| Amount of airflow   | 3.1995(g/sec) | 3.278(g/sec) |
| Oxygen content ratio| 0.232         | 0.1948       |
| Average speed       | 0.120(m/sec)  | 1.273(m/sec) |

**Figure 3.** Velocity of XZ section, Aluminium castings and iron plate metal, metal contact temperature is not higher than 60 degrees. (transparent parts: heat-resistant glass)
2.3. Mechanism simulation results
A flame structure can lift a flame to a predetermined height includes a base, a cover, and a lift mechanism. The base consists of a chamber with an opening; fuel is adapted to contain within the fuel container (figure 4). Flame produced after igniting the fuel. The cover is movably engaged with the base and selectively closes the opening. The lift mechanism includes a supporting member adapted for sliding. This supporting member being moved down from the predetermined height to the different height allow user to ignite the fuel safely and to facilitate the removal of the fuel container.

![Figure 4](image)

**Figure 4.** Perspective view of a flame device including a lift mechanism for moving a flame to a predetermined height where the cylinder is fuel tank.

![Figure 5](image)

**Figure 5.** Cross-sectional view of lift mechanism during moving a flame to a predetermined height

By lifting the alcohol tank onto the blade ring, making the product more convenient to use. As the use of lifting structure is very often, different travel range were analyzed (figure 5). Alcohol tank placed under the plane pressure of 50 Newton (alcohol tank five times the weight), because the fixed point set in the bottom of the four screw holes, the material is aluminum, were analyzed stress and deformation. Upward travel 50%, the local stress is mainly concentrated on the pin connecting area of the hitch and the push rod. The nail in the middle has a small amount of stress concentration, the maximum stress is 43.335 and the safety factor is 6.461. Note that the container keeps in horizontal posture. Hence fuel can stay inside safely.

2.4. Prototyping measurement
The redesign of the flame height is lower than the previous. Although the low diversion angle (below 40 degrees) caused outlet oxygen ratio slightly increased (complete flammability), the benefits are small. Prototyping models (figure 6) are used in the test to find better parameters. The main bodies of the ring and spiral material are steel. According to the regulations, we surveyed the most stringent CSA specification for the stove. There is specification about the glass part of the open fire, but there is no high-temperature limit. Manufacture attach warning mark on the glass. Thermal measurement Figure 6 showed average temperature of the metal chassis is 37.25°C (figure 7) which are touchable with finger; the glass temperature is 114°C which is also lower than related products. It revealed the effectiveness of the CAE flow simulation.

![Figure 6. Prototyping model with fuel tank lifting mechanism shown detail of the guide vane (where central of gravity locate: X= 0mm, Y= 0mm, Z= 132.405mm)](image)

![Figure 7. Measurement of surface temperature uses the prototyping model. Measured average temperature of the metal chassis is 37.25°C which are touchable with finger; and that of the glass: the highest part (upper section) is 141° and that of central section is 114°C](image)

3. LCA

Industry trend promoted low-carbon production. We selected life cycle assessment (Eco-indicator 99) [10] using carbon footprint as an indicator, category from cradle to the door. The module of case study contains the raw materials (mining and manufacturing), transportation, processing stage till the module is completed [11,12]. Figure 8 explodes perspective view of principal parts. The fuel is ethanol based. The cover is movably engaged with the base and selectively closing the opening. The cover (#2) includes a peripheral wall including a receptacle (#25) extended therein. The first fixing edge is
pivotally engaged with the base, with the first fixing edge pivotally engaged with the first engaging edge (#112) of the lateral wall (#11) of the base. Carbon footprints of the manufacturing stage are summarized with Eco-it in table 2. Flame module’s total carbon footprint is 9.34 KgCO₂ and that of processing stages 4.6 Kg which is 40% less than the previous model. Miniature of the flame size and guidance structure, although the mechanism added to provide new functions and keep the Carbon footprints in lower level.

![Flame module](image)

**Figure 8.** Parts of flamer (exploded perspective view) [13], where (#42) is flow guidance rib and channel, (L) indicate skew angle, (#40) is module, (#12) is base, and (#34,35) are the linkage bar.

| Part No. | Name       | Quantity | Weight (Kg) | Material     | Footprint |
|----------|------------|----------|-------------|--------------|-----------|
| 1        | Glass      | 1        | 0.921       | Glass        | 0.51      |
| 2        | Core       | 1        | 0.783       | cast iron    | 1.16      |
| 3        | Disc       | 1        | 0.402       | White iron   | 1.9       |
| 4        | Shell      | 1        | 2.082       | cast iron    | 3.1       |
| 5        | Wick       | 4        | 0.064       | Stainless steel | 0.16    |
| 6        | Light body | 1        | 0.108       | White iron   | 0.51      |
| 7        | Base       | 1        | 1.351       | cast iron    | 2.0       |

**Table 2.** Raw material carbon footprint: 9.34 (KgCO₂)

4. Conclusions
It becomes increasingly essential for company in addressing eco-performance to satisfy global environmental regulations. We use combine qualitative and CAE design process for flame device including a lift mechanism. The case study shows successful simplicity mechanism and low surface temperature. Design process helps understand natural convection and four bar linkage phenomenon.
Through the model test, modify and verify the rationality of the simulation parameters, the usability and safety features are greatly enhanced.

5. References

[1] Ramani K, Ramanujan D, Bernstein W, Zhao F, Sutherland J, Handwerker C, Choi J, Kim H, 2010 Integrated sustainable life cycle design: a review ASME J Mech Design p 132
[2] Arnette A., Brewer B, Choal T 2014 Design for sustainability (DFS): the intersection of supply chain and environment. J Clean Prod 83 p 374-390
[3] Spangenberg J, Fua-Luke A, Blincoe K 2010 Design for Sustainability (DFS): the interface of sustainable production and consumption J Clean Product 18 p 1483-1491
[4] Kara S Honke I Kaebernick H 2005 An Integrated Framework for Implementing Sustainable Product Development, Environmentally Conscious Design and Inverse Manufacturing 2005. Eco Design Fourth International Symposium p 684-691
[5] Morrison G N 1983 Thermal guide for reliability engineer, Hughes.
[6] Dave S. Steinberg, Cooling Techniques for electronic equipment, John Wiley & Sons, 1980
[7] Fauroux, J. C., Bouzgarrou, B. C., & Gogu, G. 2004. Innovative mechanism design with CAE software. In DS 33: Proceedings of E&PDE 2004, the 7th International Conference on Engineering and Product Design Education, Delft, the Netherlands, 02.-03.09. 2004.
[8] Capaldi, G., & Sinreich, M. G. (1998). U.S. Patent No. 5,809,591. Washington, DC: U.S. Patent and Trademark Office.
[9] Selyutin, L., & Zhao, J. (1999). U.S. Patent No. 5,951,776. Washington, DC: U.S. Patent and Trademark Office.
[10] Liew S K, Bray K N, Moss J B 1981 A flamelet model of turbulent non-premixed combustion. Combustion Science and Technology, 27(1-2), p 69-73
[11] PRé Consultants, Goedkoop M, Oele, M, Schryver A, Vieira M, Hegger S 2010 SimaPro Database Manual Methods library vol.2.4, p 16-17
[12] Huang Shijie, Chen Jiahao 2015 Research on Carbon Footprint Evaluation of Mechanical Equipment Products, Int. Conference on sustainability development p B-1
[13] Chen W L 2013, US Patent Pub. No. 2013/0011800 A1.