MAN-MADE SHOOTING STARS
AEROTHERMODYNAMICS AND FLIGHT DATA ON-DEMAND

Adrien Lemal[(1)], Shinzuke Abe[(2)], Koh Kamachi[(3)], Lena Okjima[(4)]

[(1)]Astro Live Experiences, 2-21-1 Akasaka, Minato-ku, 107-0052 Tokyo, Japan, E-mail: adrien.lemal@star-ale.com
[(2)]Nihon University, 7-24-1 Narashinodai, Funabashi, 274-8501 Chiba, Japan, E-mail:avell@aero.cst.nihon-u.ac.jp
[(1)]Astro Live Experiences, 2-21-1 Akasaka, Minato-ku, 107-0052 Tokyo, Japan, E-mail: koh.kamachi@star-ale.com
[(1)]Astro Live Experiences, 2-21-1 Akasaka, Minato-ku, 107-0052 Tokyo, Japan, E-mail: lena.okajima@star-ale.com

ABSTRACT

This paper reports the activities undertaken at Astro Live Experiences (hereafter referred as ALE) to engineer a spherical particle composed of non-toxic confidential materials which will fully extinct after emitting light by leveraging the aeroheating and ablation withstand during their entry into Earth's atmosphere. The present work briefly describes the nonequilibrium fluid dynamics, ablation and radiative transport simulations as well the experimental campaigns carried out at JAXA-ISAS arc-jet facility under representative heating conditions. The combination of the simulations and experiments demonstrated that the particle brightness is comparable to stars visible by the naked eye and fully disappear above 80km ensuring customer satisfaction and safety.
Moreover, the man-made shooting stars are believed to provide significant amount of various flight data, which can be used to address the current issues of space debris mitigation, heat shield design optimization, foreign body detection and meteor sciences, which would trigger contracts and partnerships between ALE and top-notched agencies, companies, research centres and universities world-wide.

1. INTRODUCTION

Space policies and businesses have been essential in enhancing our daily life thanks to observation, telecommunication, navigation services. However, only of few of us are knowledgeable in space business as the use of space has not been maximized yet. At ALE, we aim to take on the challenges posed by an increasingly competitive industry and an ultra-connected society. Our game-changing approach enables us to envision to anchor space in our culture to propel man-kind to new endeavours. ALE will expand man-kind horizons, bridge multi-disciplinary fields and transcend space to a new dimension by putting emphasis on art, culture and entertainment. ALE combined off-the-shelf satellites technologies, Japan craftmanship and meteor sciences to design a shooting star technology which will provide an unprecedented entertainment to the people on ground and measure data in the mesosphere. The present paper aims at introducing the computational, experimental studies and results about shooting star aerodynamics, ablation and brightness as well as the flight data to be measured during the observation campaigns.

2. COMPUTATIONAL STUDIES

The brightness of the shooting star is a multi-physics, multi-scale problem, which requires significant computing power and adequate boundary conditions. In the present work, a loosely-coupled hybrid approach relying of sequential computation of mass change, aerodynamics and radiation was followed.

2.1 Trajectory

The trajectory of the particle as well as its mass evolution during its entry into Earth's atmosphere were computed with Tokyo Metropolitan University's in-house code [1], which relies on the works from [2, 3]. From the works of [1], the most influential parameters were the drag and heat transfer coefficients; thus, a sensitivity analysis was subsequently pursued in [4]. The convective heat flux was computed with the Detra-Kemp-Riddell equation [5] and the surface temperature was determined assuming radiative equilibrium.

2.2 Aerothermochemistry

The flow surrounding the particle was computed with JAXA Navier-Stockes nonequilibrium flow code [6], which solves the conservation of species mass, momentum, total and electron-vibration energies. As the particle radius decreases during the trajectory because of mass loss, the Knudsen number increases and drove the implementation of Maxwell slip boundary conditions [7].

2.3 Radiation transport

The shooting stars brightness, which is used for entertainment and science purposes, is governed by the spectral properties of the material in its various phases, the air plasma and the components resulting from their interaction and chemical reactions. The transition

probabilities of atomic lines were taken from the NIST database [8]. The transition probabilities of molecular bands were computed following the works of [9-11]. The radiation transport equation was solved along lines of sight departing from the shooting star to the ground. The intensity was finally converted into magnitude, as described in [12].

3. EXPERIMENTAL CAMPAIGNS

As depicted in Fig. 1, the 1MW arc-jet facility at JAXA-ISAS [13] was equipped with emission spectroscopy diagnostics as well as high speed cameras [14, 15] and used to characterize the thermal and mechanical response as well as the brightness of various materials ranging from metals, ceramics, meteorites to further support the design of ALE shooting star mixture [16, 17] and engineer the particle outer shell. The material mass loss rates, temperature diffusion, as well as the thermodynamic state of the plasma were inferred from measured spectra and were used to assess the performances of the computational models and strengthen the accuracy of the shooting star entry peak brightness and demisability altitude [18].

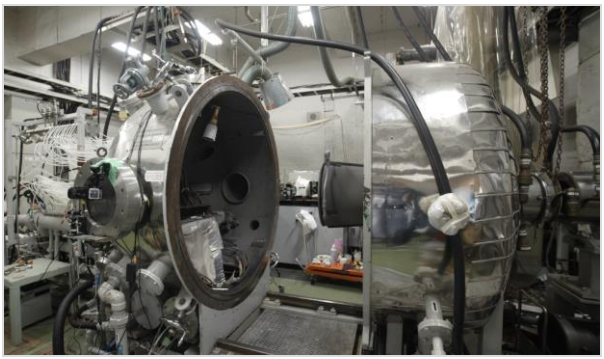

Fig. 1: JAXA-ISAS arc-jet facility

4. RESULTS

4.1 Trajectory

Fig. 2-4 display the velocity, convective heat flux and radius profiles during the shooting star trajectory, respectively. Peak convective heating occurs at 73 km.

4.2 Aerothermochemistry

Fig. 5 displays the flow variables at peak heating. The air temperatures in the wake were found negligible with respect to the material phase temperatures.

4.3 Radiation transport

Fig. 6 displays the emitted power from various confidential materials as a function of their temperature and suggests the existence of an optimized mixture generating the greatest brightness.

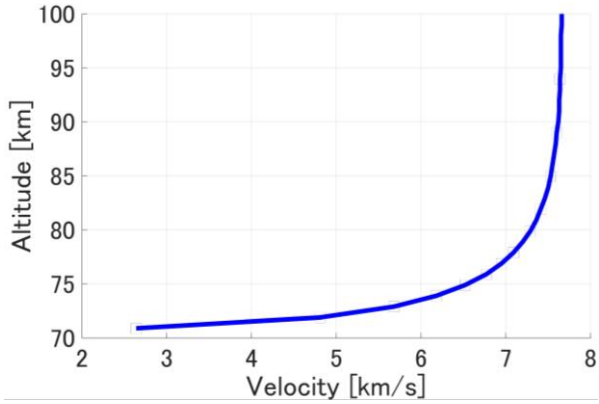

Fig. 2: Velocity profile

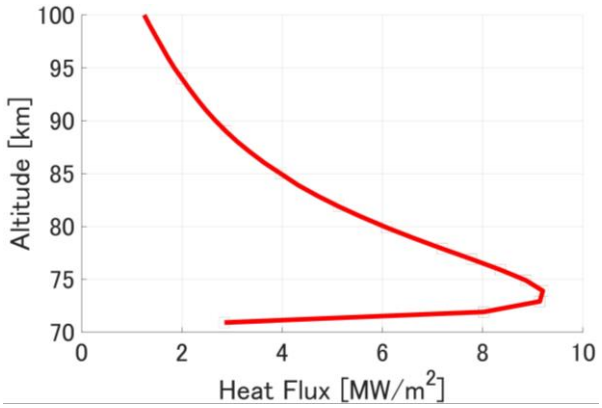

Fig. 3: Convective heating profile

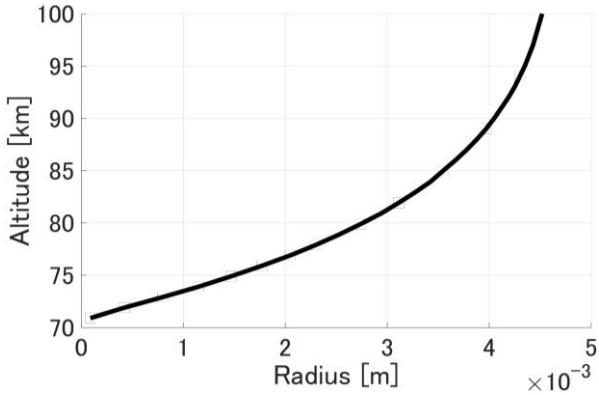

Fig. 4: Radius profile

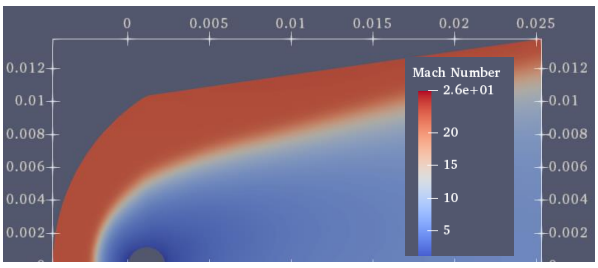

Fig. 5: Mach number colour plots

4.4 Material brightness

Fig. 7 and 8 display the observed and computed brightness from different materials, respectively. Colours ranging from green, orange, blue could be obtained.

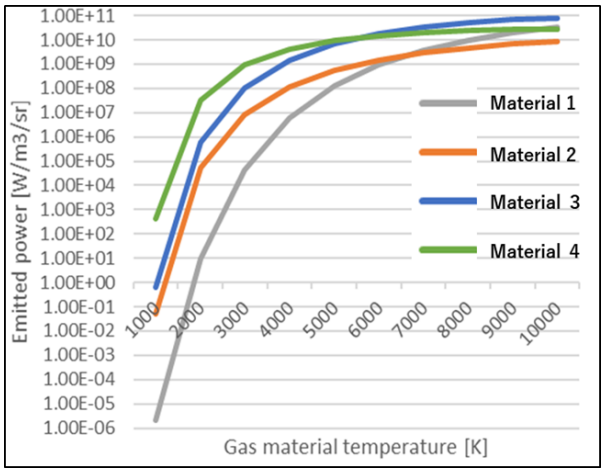

Fig. 6: Material emitted powers

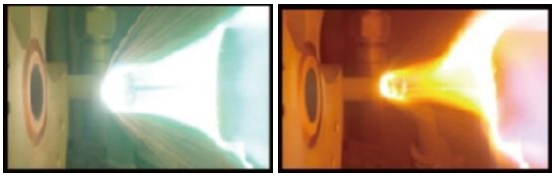

Fig. 7: Observed material brightness

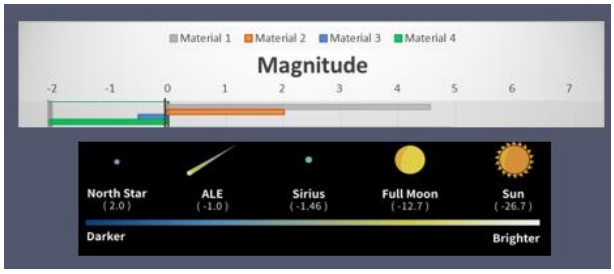

Fig. 8: Simulated material brightness

5. ON-DEMAND FLIGHT DATA

Flight data are scarce, which hinders the development of optimized, reliable and cost-effective spacecraft and the accurate determination of space debris demise altitude and features. Determining the mass, composition and entry velocity of natural meteors from observation is complicated and warrants iterative procedures. To tackle this issue, ALE developed a unique shooting star technology based on the release of hundreds of particles of known mass, composition, trajectory from constellation of satellites. ALE was selected by JAXA to be part of the 'Innovative Satellite' program [19, 20] and was granted the launch of its first satellite, ALE-1, on board of JAXA Epsilon #4 in Jan. 18th 2018. ALE-1 launch was successful and communication with the ground station in Tohoku University was fully established. Lessons learnt from the in-orbit tests of space systems have also been successful and fruitful to speed-up the design of ALE second satellite. Its integration and launch into a private launcher are forecast in autumn 2019. In spring 2020, ALE satellites will reach their final orbit and release hundred of particles above in the sky of Hiroshima, as displayed in Fig. 9, to entertain the people and give the opportunity to world-wide researchers to carry out their observation campaigns.

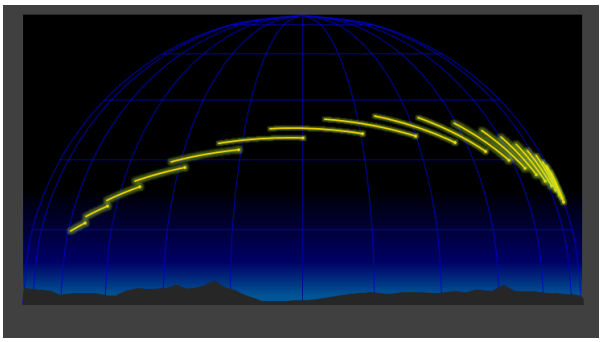

Fig. 9: Shooting star patterns

Emission spectra as well as radar signature are forecast to be used to infer material composition change and chemical reactions occurring in the air plasma and further advance the knowledge of emission, fragmentation and energy conversion processes to contribute to weather forecast, heat shields optimization, meteor sciences, foreign body detection and space debris demise.

ALE welcomes contracts and partnerships with agencies, companies, research centres and universities world-wide and will be delighted to give them the opportunity to fly-test their space systems and materials and analyse their behaviour under severe conditions.

6. CONCLUSIONS

The present paper introduced ALE's core computational, experimental and engineering capabilities in the design of satellites, payloads and man-made shooting star particles to deliver an unprecedented entertainment and further promote space technologies, science and businesses as well as to measure a significant amount of various flight data of high repeatability to advance atmosphere and aerospace sciences.

Ongoing works encompass the development of flow-ablation coupled simulations, the piloting of arc-jet campaigns as well as the development of A.I-based data analysis algorithms and software.

7. REFERENCES

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