

ALSET - Japanese Air Launch System Ground Tests and Applications

Kohei OKAMURA, Yuichi NOGUCHI, Seiji MATSUDA
IHI AEROSPACE Co., Ltd.
900, Fujiki, Tomioka-shi, Gumma 370-2398 Japan; +81-274-62-7681
kohei-okamura@iac.ihi.co.jp

Takayoshi FUJI
Japan Space Systems
3-5-8, Shibakoen, Minato-ku, Tokyo 108-0023 Japan; +81-3-6809-1492
Fuji-Takayoshi@jspacesystems.or.jp

Hideki KANAYAMA
CSP Japan Inc.
Shibaura Shimizu Building, 4-15-33, Shibaura, Minato-ku, Tokyo 105-0011 Japan; +81-3-6453-9003
kanayama@csp.co.jp

Jon WALLACE
SpaceWorks Enterprises Inc.
1040, Crown Pointe Parkway, Suite 950, Atlanta, GA 30338 U.S.; 404-991-2201
jon.wallace@sei.aero

ABSTRACT

The Air Launch System Enabling Technology (ALSET) project is a Japanese Ministry of Economy, Trade and Industry (METI) funded project whose purpose is to study air launch orbital payload delivery systems and related technologies. The project is a first step toward an operational commercial air launch system that will use a multistage solid rocket to deliver small payloads on the order of 100 to 200 kilograms into Low Earth Orbit (LEO).

An air drop type launch approach to space transportation provides high reliability, flexibility, and responsiveness to meet the future needs of small satellite operators. ALSET culminates in a series of drop tests of an inert launch vehicle (a mass simulator) to demonstrate the technologies necessary for the operational system.

The baseline system design uses a carriage extraction system method whereby the rocket is extracted from a C-130 aircraft on a TYPE-V platform. Two 28-foot extraction parachutes are used to pull the platform from the aircraft. Three 100-foot cargo parachutes are then deployed for deceleration prior to release of the rocket from the platform for launch.

The baseline test site selected for the drop test is the Yuma Test Center (YTC) in Arizona, USA. The large drop zones available at the YTC are ideal for ALSET testing. Additionally, the YTC's considerable experience with similar test activities, including the NASA Ares Jumbo Drop Test Vehicle drop tests, minimizes technical risks.

The authors' efforts to date completed the Critical Design Review (CDR) for the ALSET Drop Test in February and March 2015. The ALSET program is now ready for manufacturing for the ALSET Drop Test.

As the prospective applications of ALSET to C4ISR missions, two case studies were conducted. The studies demonstrated the effectiveness of the air launch system. The responsiveness and flexibility of the air launch system enables small satellites to collect the ground information desired in short time, and to observe the target high-frequently by sequential satellite launches and forming a constellation.

1. INTRODUCTION

ALSET is a Japanese government-funded (funded by the Ministry of Economy, Trade and Industry, or METI) project whose purpose is to study air launch orbital payload delivery systems and related technologies as a first step toward an operational commercial air launch system. Air launch was selected instead of ground launch for the following reasons: (1) fewer restrictions and improved safety of air launch by avoiding flight over occupied land (islands) and fishing boats, (2) flexibility of launch point to meet demand for delivery of payload to various orbits and (3) reduced cost of ground launch support operations achieved through decreased infrastructure. Plans call for the operational system to air-launch multistage solid rockets from an existing large transport aircraft to deliver small payloads on the order of 100 to 200 kilograms into Low Earth Orbit (LEO).

The Critical Design Review (CDR) for the ALSET Drop Test, including the review by L-3 Coleman Aerospace on the safety point of view was completed in February and March 2015. During the detailed design activities, the ALSET Ground Tests were executed in Japan from November 2014 to January 2015 for verification of designs for some critical items. The

results of the ALSET Ground Tests are shown in Chapter 4. The ALSET program is now ready for manufacturing for the ALSET Drop Test.

2. AIR LAUNCH SYSTEM OVERALL CONCEPT

The primary air launch technology development areas of the ALSET project are: (1) air launch system overall concept definition, (2) air launch technology research and method selection, (3) air launch system operations study, (4) GPS ranging and satellite-based telemetry, tracking, and control study, and (5) low cost and light-weight launch vehicle avionics study.

Figure 1 shows the ALSET air-launch system concept and associated air launch technologies. The launch vehicle is loaded onto a cargo aircraft at an airport and ferried to the launch point. During ferry, GPS for ranging is initialized, and satellite communication link for TT&C is established inside the aircraft. The launch vehicle is dropped from the aircraft by an air drop system, decelerated by parachutes, and separated from the parachutes for launch. The launch vehicle consists of a three-stage solid rocket motor to place the satellite into a low earth orbit. GPS and satellite communication links remain active until separation of the satellite from the launch vehicle after third stage burn-out.

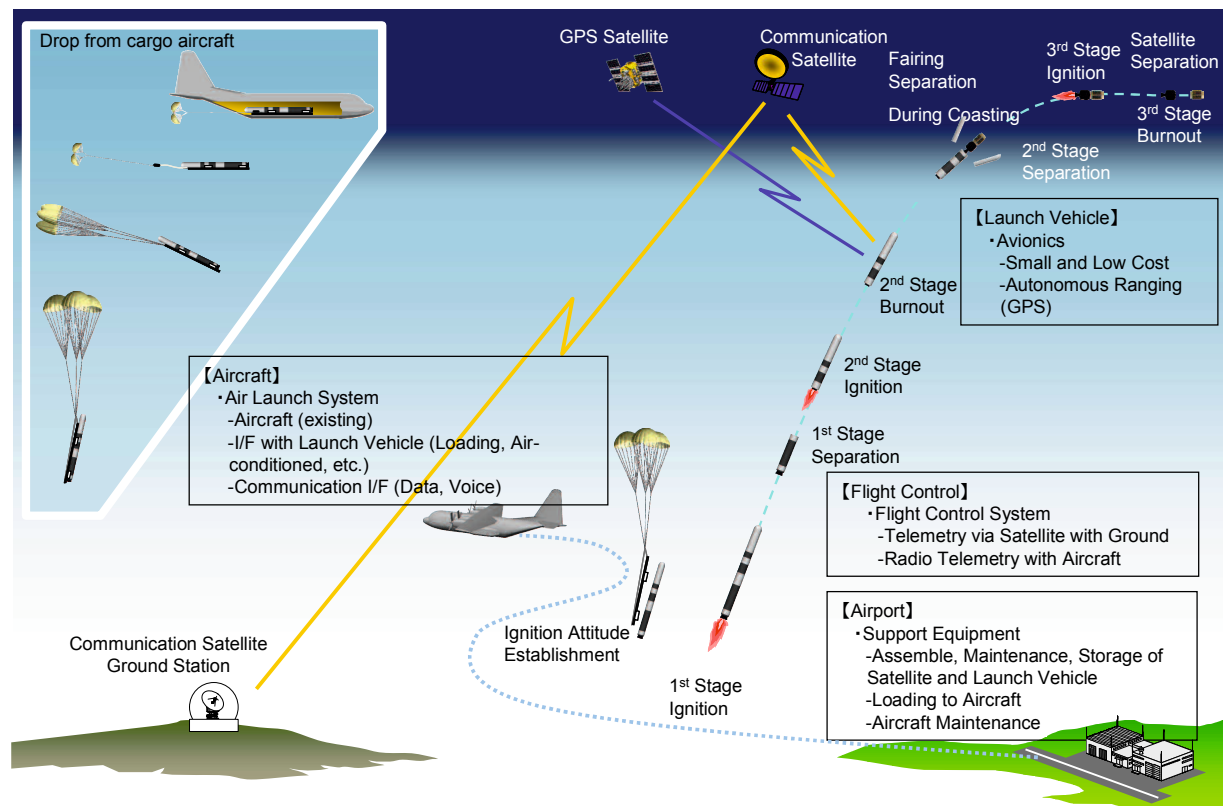


Figure 1: Air Launch System Overall Concept

Three types of air launch methods were studied during this project: air drop, subsonic horizontal launch, and supersonic zoom launch. It was determined as a result of this study to select the air drop method for ALSET to take advantage of existing and proven aerial cargo delivery systems. Since many cargo aircraft, including the C-130, the C-17 and the C-2 (under flight testing by Japan Air Self-Defense Force (JASDF)) already or will use the TYPE-V platform, minimal aircraft modification is necessary, and minimal verification tests are necessary with respect to aircraft safety because of no aerodynamic interference between aircraft and launch vehicle (Ref. 1).

3. AIR LAUNCH SYSTEM OVERVIEW

3.1. Mission

The reference mission is to deliver a 150 kilogram satellite to a polar circular orbit (the inclination is around 90 degrees) at altitude 500 kilometers.

Launch capability shown in Figure 2 is that of the air launch rocket described in Section 4.1. It is just the right capability for small satellites for ongoing and highly increasing Earth observation mission or responsive space mission.

Companies such as Skybox Imaging and GeoOptics are starting services for Earth imaging with a small satellite constellation. Skybox Imaging is planning to launch 24 120-kilogram small satellites into the 500-kilometer altitude Sun-synchronous orbit with launch vehicles such as PSLV and Minotaur-C to build a small satellite constellation for their mission.

The air launch system is able to respond their future demands for rapid replacement of small satellites that have reached the end of their lifetimes or have malfunctions in orbit.

3.2. Sequence of Events

The sequence of events for the air drop is shown in Figure 3.

- (1) When the aircraft is approaching an airdrop point, the cargo room is depressurized to open the cargo door,
- (2) the cargo door is opened,
- (3)(4) the TYPE-V platform is extracted by two 28-foot extraction chutes based on the C-130 E/H standard air drop procedures,
- (6) the extraction force is transferred and the cargo chute assembly is deployed,
- (7) the parachute platform is released,
- (8) the system drops and is decelerated by the cargo chutes with disreefing,
- (9) the rocket attitude is changed for the separation attitude arrangement,
- (10) the rocket is separated from the platform.

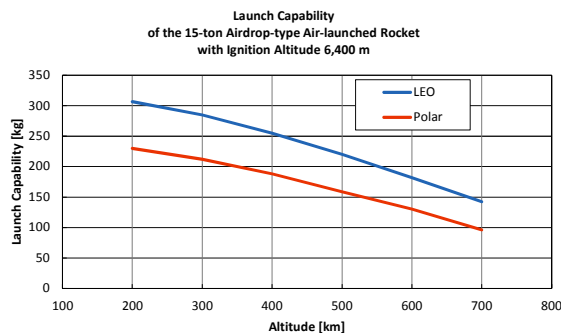


Figure 2: Launch Capability

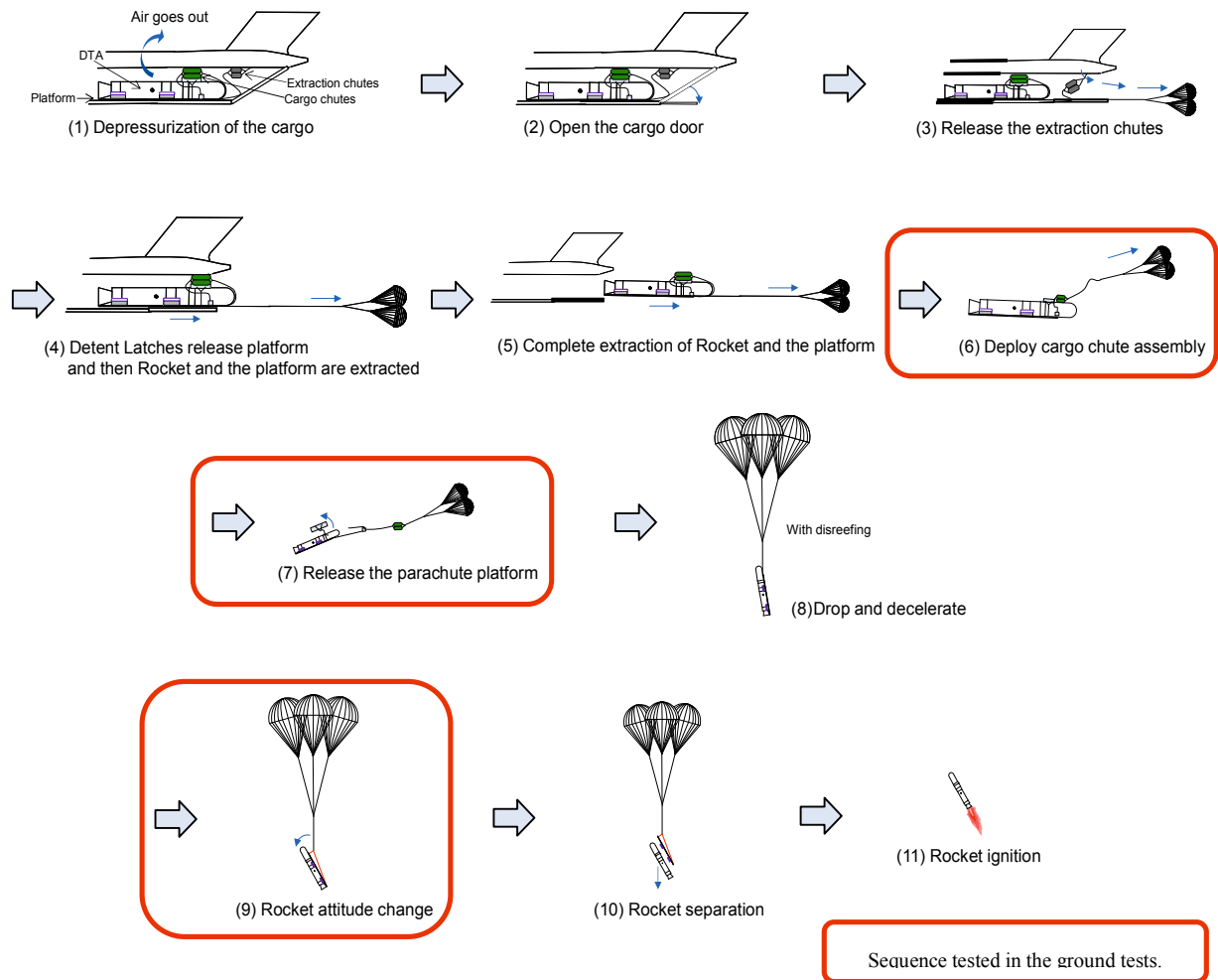


Figure 3: Sequence of Events

4. AIR LAUNCH SYSTEM CONFIGURATION

The air launch system consists of an air launch rocket and a carriage extraction system (CES).

The system configuration at loading in a C-130 E/H aircraft is shown in Figure 4.

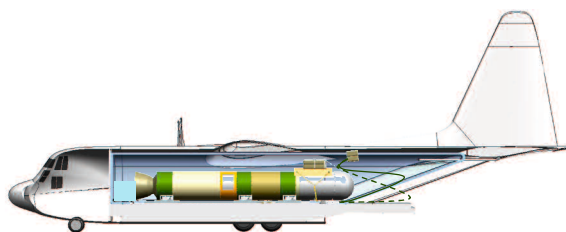


Figure 4: System Configuration at Loading in a C-130 E/H

4.1. Air Launch Rocket

The air launch rocket system was designed to be responsive and uses solid rockets for all stages. The major specification and overview is shown in Table 1 and Figure 5.

Table 1: Major Specification for the Air Launch Rocket

Item	Value
Dimension	ϕ 1.5 m x L 11 m
Mass	15,000 kg (excl. satellite mass)
Launch Capability	Polar Orbit (Alt. 500 km Cir.) 150 kg +

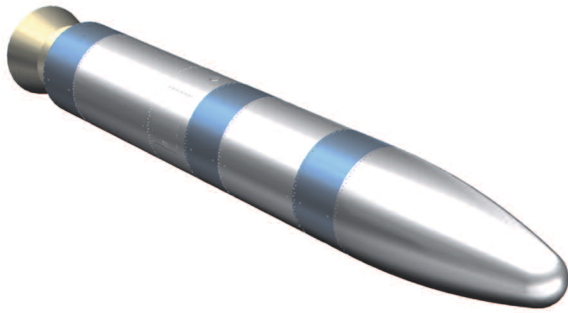


Figure 5: Air Launch Rocket Overview

4.2. Carriage Extraction System (CES)

The Carriage Extraction System (CES) overview is shown in Figure 6.

To minimize aircraft modification and verification tests for the system, the CES basically employs the C-130 E/H standard air drop equipment such as the TYPE-V platform, two 28-foot extraction chutes and the extraction line.

The air launch rocket is attached to the platform with the cradles. The cradles are made of aluminum alloys, steel alloys and aluminum honey comb panels. The cradles restrain the rocket until the time for separation comes, and release the restraints when the time comes by activating separation nuts.

The newly designed cargo chutes are geometrically similar to the US Army G-11, but with increased strength and load capacity. These parachutes are stowed atop the rocket on the parachute platform (PPF). The PPF is mainly made of paper honey comb sandwich panels for achieving specific strength compatible with the requirement. The PPF is released during deploying harnesses between the cargo chutes and the platform.

The CES includes equipment for the attitude change of the rocket during descent, devices for the sequence control. The CES can interface with C-130 E/H by the TYPE-V platform. The CES complies with the requirements and constraints for C-130 E/H.

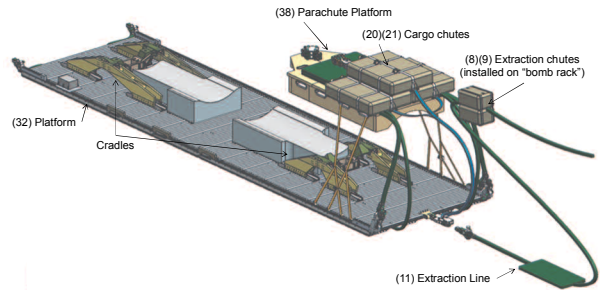


Figure 6: CES Overview

4.3. Extraction and Deceleration Analysis

Extraction and deceleration analyses were performed separately because of necessity of model maturity (Ref. 2). The objectives of extraction analysis are to examine extraction motion and determine initial conditions of deceleration analysis. The objectives of deceleration analysis are to examine drop motion after extraction, coupled motion of launch vehicle and cargo parachutes, and to determine the nominal timeline from deceleration through the 1st stage ignition.

The model for each analysis is shown in Ref. 3. The analyses include consideration of disturbance such as aircraft characteristics and gusts.

The extraction analysis shows the initial conditions of the deceleration analysis. It also concludes the air launch system is able to safely extract the cargo including the rocket, even if the disturbance may occur.

As a result of the extraction and deceleration analysis, the sequence of events from Extraction Start to Rocket Ignition was set for the drop test. One of the typical analysis results is shown in Figure 7.

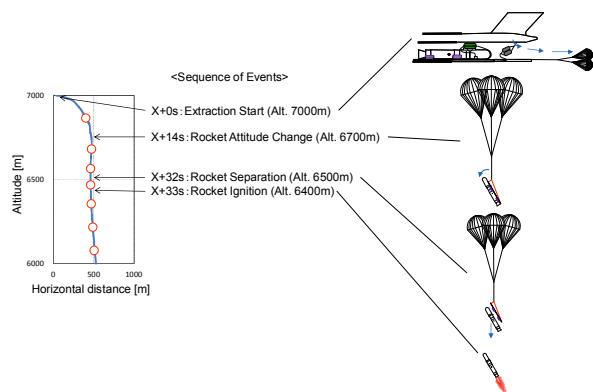


Figure 7: Deceleration Analysis Result

4.4 Ground Tests

The ALSET Ground Tests were conducted in Japan from November 2014 to January 2015 with the objective of completing the detailed designs for some critical items such as the cargo chutes, risers and harnesses. Figure 8 shows a test article for the ground tests. The article consists of a partial mockup of a rocket, the PPF, the cargo chutes and other air drop equipment.

The ground tests demonstrated: 1) the airdrop equipment, especially “parachute system” (the cargo chutes, the PPF, etc.) is loaded without any interference. The rigged configuration meets the requirements and constraints of the C-130 E/H, 2) the air drop equipment such as the cargo chutes and the risers and harnesses is extracted and deployed as designed without any interference, 3) the PPF is released as envisioned, and

4) the adapters for the rocket attitude change work as designed when the rocket attitude change motion occurs.

The typical snapshots of the ground tests are shown in Figure 9 and 10.

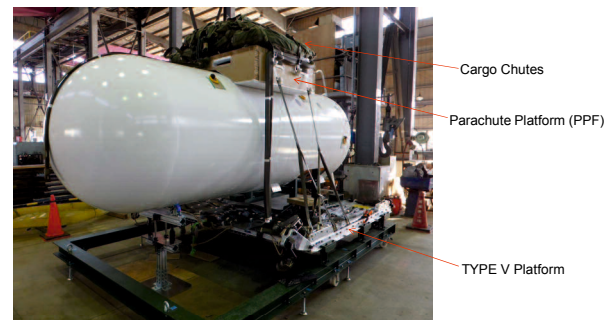


Figure 8: Test Article for the Ground Tests

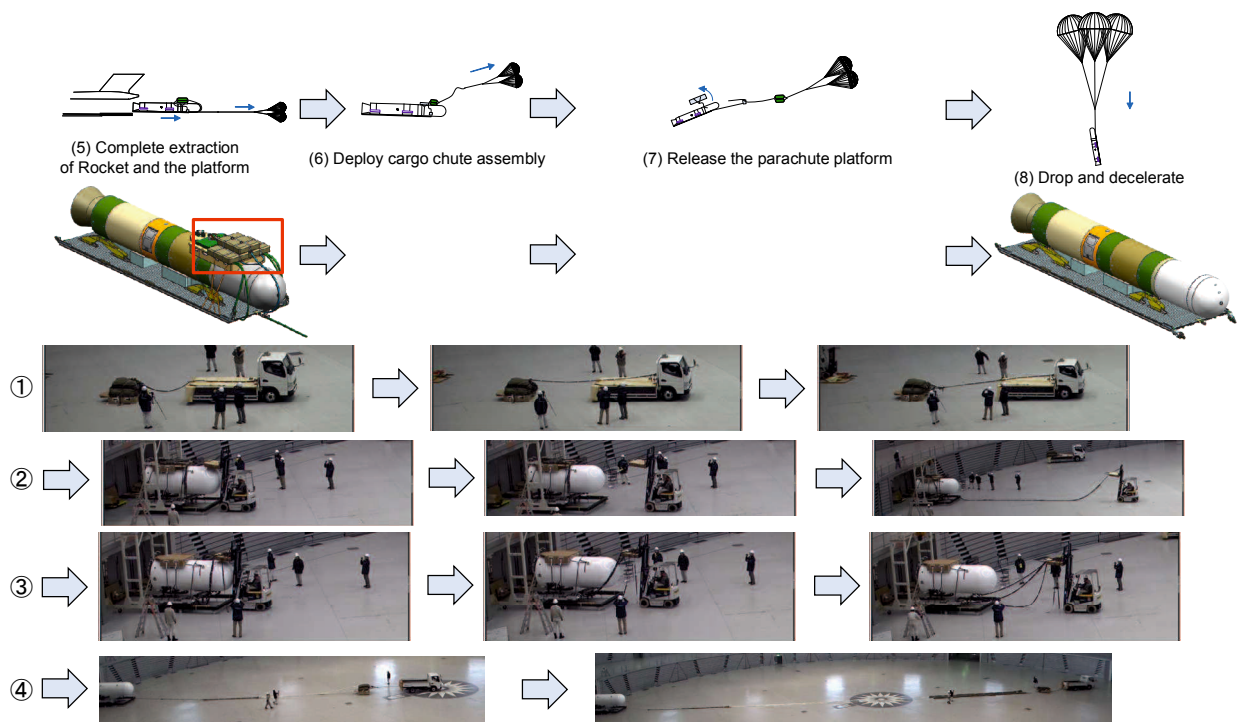


Figure 9: Cargo Chutes Deployment

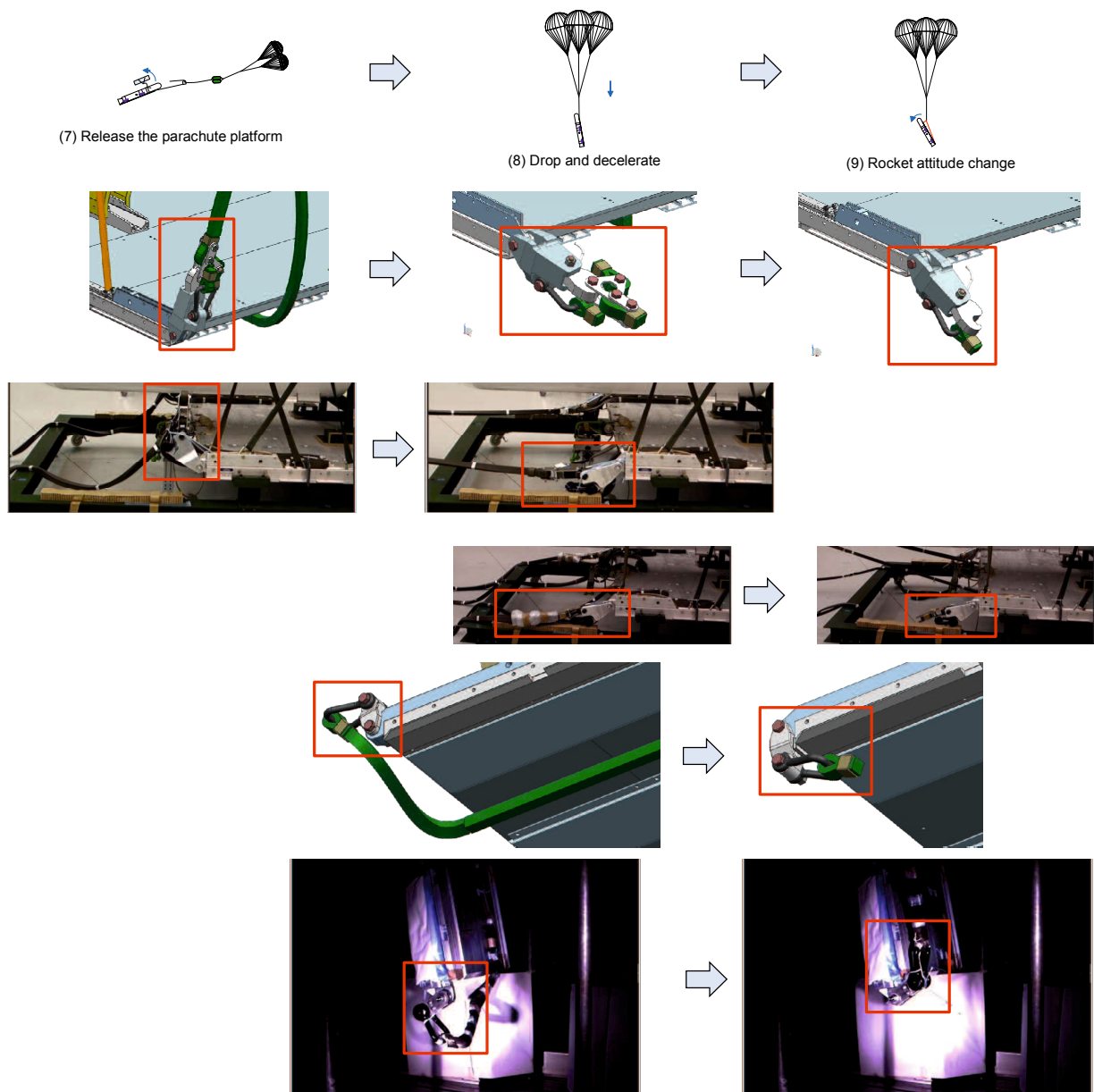


Figure 10: Rocket Attitude Change

5. DROP TEST PLAN

The ALSET program endeavors to perform initial technology development and operational planning for a commercial air launch system. As a key part of the ALSET program, it is desired to conduct an initial air drop test of an instrumented inert rocket in the United States. The ALSET drop test is expected to involve release/extraction of the test article from the cargo aircraft, stabilization of the test article under descent parachutes, and separation of the Drop Test Article (DTA) from the Carriage Extraction System (CES). The baseline drop test scenario is planned to be conducted at an altitude of about 7,000 meters (23,000 feet), if possible. An overview of the drop test sequence is shown in Figure 11. The C-130 E/H model has been selected as the baseline aircraft for the ALSET drop test. The baseline test site selected for the drop test is the Yuma Test Center (YTC) operated by the US Army in Arizona. The large drop zones available at the YTC are ideal for ALSET testing. Additionally, the YTC's considerable experience with similar test activities, including the NASA Ares Jumbo Drop Test Vehicle drop tests, minimizes technical risks.

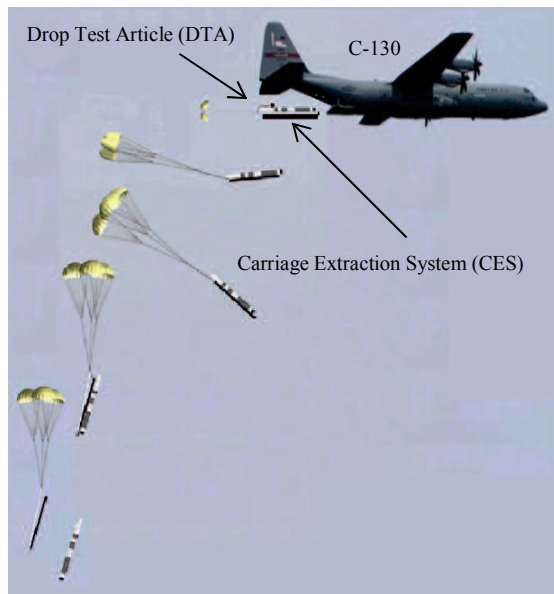


Figure 11: ALSET Drop Test Overview

The primary objective of the ALSET drop test is to verify that the designed air launch rocket and extraction system will descend stably and will separate as envisioned. The objectives for drop test data collection broadly fall into three categories as follows: (1) demonstrate the air drop sequence of events, (2) collect engineering data on the dynamics of the air drop and (3) collect environment data under which the test is conducted. The top-level data collection objectives for

which the instrumentation system must be designed are provided in Table 2.

Table 2: Drop Test Objective Breakdown

No.	Test Objective
1	Demonstrate Sequence of Events
1.1	Verify extraction start
1.2	Verify activation of EFTC
1.3	Verify cargo parachute bag release
1.4	Verify platform separation
2	Collect Engineering Data
2.1	Measure 3-axis angle
2.2	Measure 3-axis angular rate
2.3	Measure 3-axis angular acceleration
2.4	Measure 3-axis linear acceleration
2.5	Measure extraction force
2.6	Measure cargo parachute load
3	Collect Environment Data
3.1	Measure location
3.2	Measure atmospheric pressure
3.3	Measure atmospheric temperature
3.4	Measure wind velocity and direction
4	Collect Still Photos and Video
4.1	Take video images
4.2	Take photographic images

Test organizations and responsibilities of the ALSET drop test are shown in Figure 12. The Test Support Organization (TSO) is a US-based supplier of air drop test support services to facilitate execution of the ALSET drop test. The Instrumentation Provider (IP) is a US-based supplier of air drop test instrumentation subsystem to perform engineering data collection for the ALSET drop test.

The ALSET drop test image is shown in Figure 13.

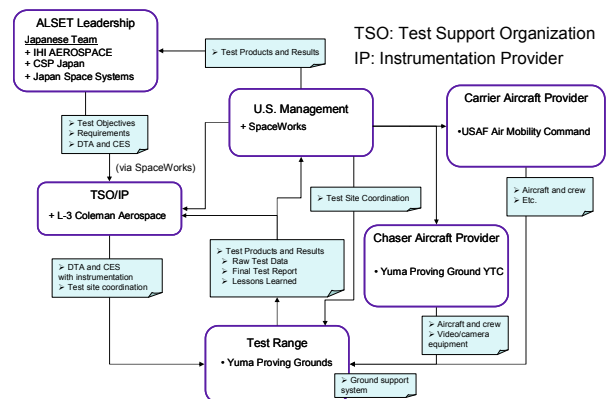


Figure 12: ALSET Drop Test Organizations and Responsibilities



Figure 13: ALSET Drop Test Image

6. AIR LAUNCH SYSTEM APPLICATIONS

The air launch system has high responsiveness and flexibility. It is expected to apply to small satellite observation mission for C4ISR.

This section shows the capability of following mission achieved by small satellites launched by the air launch system: (1) responsive observation to collect information about flexible points in short time and (2) high-frequency observation to collect information about a fixed point by constellation of small satellites.

6.1. Responsive Observation

Figure 15 shows a typical result of case study on area which an air-launched small satellite can observe. The observation time is 65 to 100 minutes from the launch.

In this case study, assumptions are: (1) the launch site is in “Charlie” water area, (2) the launch azimuth is 35 to 155 degrees, in which direction there are no lands and islands within 3000-kilometer distance, (3) the satellite orbital altitude is 300 kilometers and the sensor FOV is ± 60 degrees, (4) the satellite is able to start observation in about 1 hour from the launch.

The information desired can be collected flexibly in 1.5 hours by using the air launch system.

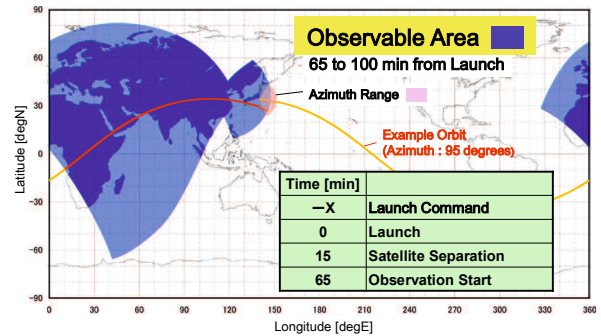


Figure 15: Responsive Observation

6.2. High-frequency Observation by Constellation

Figure 16 shows a typical result of case study on observation frequency which a constellation of small satellites can observe. In this case study, Mt. Aso, whose volcanic alert level is “Level 2”, was chosen as the target point (Ref. 7). The top of Figure 16 shows the footprint of the satellites and the target observing point. The bottom of Figure 16 shows the observation frequency.

In this case study, assumptions are: (1) the orbital recurrence period is 5 days, (2) five satellites are launched by the air launch system sequentially in an interval of 5 hours.

This constellation is capable of observing the target point high-frequently every 1 to 5 hours.

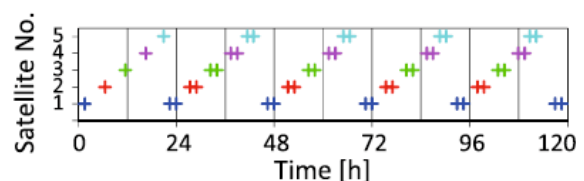
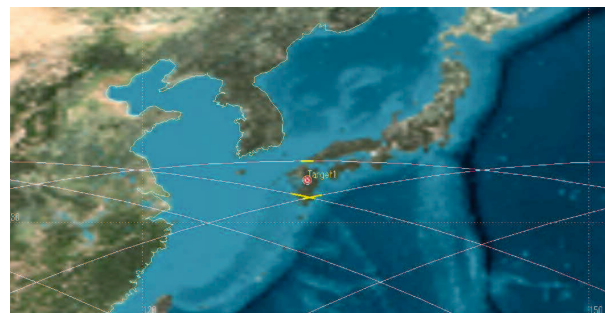


Figure 16: High-frequency Observation by Constellation

7. CONCLUSION

To respond to increasing demand for small satellite dedicated space launch, an air launch system has been chosen through several trade studies as a preferred pathway for such a system as part of the Japanese ALSET project. After some design activities, the air launch system configuration was settled for upcoming the ALSET drop test. For the ALSET project, the air drop test is planned to demonstrate utilizing air launch for a future, operational space access system.

The CDR for the ALSET Drop Test was completed in February and March 2015, and the ALSET Ground Tests were conducted from November 2014 to January 2015. The ALSET program is now ready for manufacturing for the ALSET Drop Test.

As a result of the case studies on the air launch system applications to C4ISR missions, the effectiveness of the air launch system was demonstrated. The ground information desired can be collected in 1.5 hours from the launch, and the constellation consisting of 5 small satellites launched by the air launch system is capable of observing the target point every 1 to 5 hours.

ACKNOWLEDGMENTS

The authors would like to thank L-3 Coleman Aerospace for support to the ALSET project provided to date. In the role of TSO and IP, L-3 Coleman Aerospace assisted with the system requirements and definition phase through the detailed design phase by completing a design for the drop test instrumentation subsystem, and by providing safety-critical feedback on the air drop system design. In particular, the authors would like to thank Mr. Stan Haynes, Program Manager for the activities at L-3 Coleman Aerospace.

REFERENCES

1. T. Arime, M. Sugimine, S. Matsuda, J. Yokote, T. Fuji, K. Sasaki, D. DePasquale, H. Kanayama and M. Kaneoka, "ALSET - Air Launch System Enabling Technology R&D program," 25th Annual AIAA/USU Conference on Small Satellites, SSC11-II-5, 2011.
2. Maurice P. Gionfriddo, "Aerodynamic Decelerator Systems Technical Committee Effort to Archive Parachute Technology," 21st AIAA Aerodynamic Decelerator Systems Technology Conference, AIAA 2011-2500, 2011.
3. Y. Noguchi, T. Arime, S. Matsuda, T. Fuji, H. Kanayama and D. DePasquale, "Japanese Air Launch System Concept and Test Plan," 22nd AIAA Aerodynamic Decelerator Systems Technology Conference, AIAA 2013-1331, 2013.
4. Y. Noguchi, T. Arime, S. Matsuda, T. Fuji, H. Kanayama and D. DePasquale, "Japanese Air Launch System Concept Design," 29th International Symposium on Space Technology and Science, 2013-o-3-03, 2013.
5. Y. Noguchi, T. Arime, S. Matsuda, T. Fuji, H. Kanayama and D. DePasquale, "ALSET - Japanese Air Launch System Concept and Test Plan," 27th Annual AIAA/USU Conference on Small Satellites, SSC13-V-7, 2013.
6. Y. Noguchi, S. Matsuda, T. Fuji, H. Kanayama and J. Wallace, "Air Launch System Enabling Technology (ALSET) Program Overview," 30th International Symposium on Space Technology and Science, 2015-o-6-04, 2015.
7. Japan Meteorological Agency, "Volcanic Warnings," <http://www.jma.go.jp/en/volcano/> (June 15th, 2015)