SSC13-V-7

ALSET - Japanese Air Launch System Concept and Test Plan

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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.

This paper will show the progress of system design and drop test planning. Trade studies are presented leading to a baseline system design and concept of operations. Factors considered in the trade studies include aircraft/launch vehicle interface, extraction and deceleration methods, and operational regulations.

Commercial concept of operations to respond the demand to launch small satellites with responsiveness, advantages of the air launch system over existing launch system will be shown in this paper.

The baseline system design uses a carriage extraction system method whereby the rocket is extracted from the aircraft on a carriage. A 15-foot pilot parachute is used to draw two 28-foot extraction parachutes and pull the carriage from the aircraft. Three G-11 cargo parachutes are then deployed for deceleration prior to release of the rocket from the carriage 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.

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).

AIR LAUNCH SYSTEM TECHNOLOGIES AND 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.

Three types of air launch methods were studied during this project: air drop, subsonic horizontal launch, and supersonic zoom launch. It was decided 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, already 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).

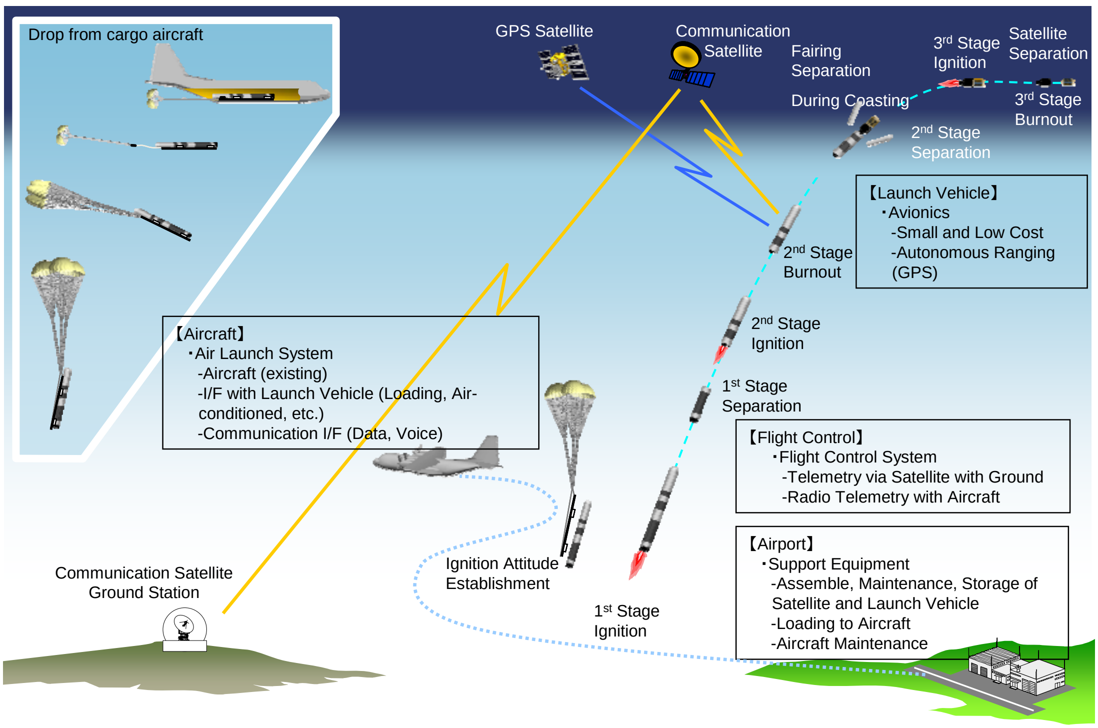


Fig. 1. Air Launch System Overall Concept.

AIR DROP SYSTEM SELECTION

The authors completed a preliminary design of the launch vehicle that satisfies the air drop capability and loading limits of the cargo aircraft (C-130). The outer mold line of the launch vehicle is shown in Figure 2. The drop test will use an inert, instrumented, mass simulator of this vehicle. The mass simulator is termed the Drop Test Article (DTA). The other portion of total drop system, including the extraction platform, cradles, and parachutes is termed the Carriage Extraction System (CES). A picture of the total drop system, DTA and CES is shown in Figure 2. Mass properties of the drop system are shown in Table 1.

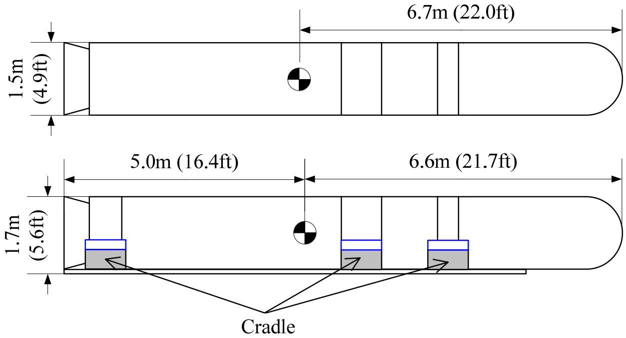


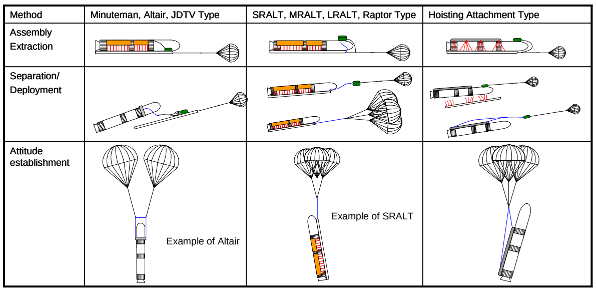
Fig. 2. DTA Outer Mold Line and DTA with CES.

Table 1. Mass Properties.

Item			Value
Dimension	DTA		φ1.5 m x 11.6 m (φ4.9 ft x 38.1 ft)
	DTA and CES		1.7 m (H) x 2.7 m (W) x 11.6 m (L) (5.6 ft (H) x 8.9 ft (W) x 38.1 ft (L))
Mass	DTA (including instrumentation)		16,500 kg (36,400 lb)
	DTA and CES		19,000 kg (41,900 lb)
Center of Gravity	DTA		6.7 m from the tip of the DTA (22.0 ft)
	DTA and CES		6.6 m from the tip of the DTA (21.7 ft)
Moment of Inertia	DTA	Ixx	4,744 kg-m^2 (112,577 lb-ft^2)
		Iyy	137,356 kg-m^2 (3,259,507 lb-ft^2)
		Izz	137,356 kg-m^2 (3,259,507 lb-ft^2)

The authors also studied the method for assembly, loading, and separation by surveying existing methods employed for air drop systems. The investigation found that the method could be divided into three types (shown in Table 2). The characteristics and design considerations of each type are described below.

Table 2. Assembly, Loading and Separation Method



Minuteman, Altair, JDTV Type

This type will unlash the launch vehicle while horizontal velocity remains after extraction. There will be low probability of collision between the platform and aircraft because the platform will be separated by time delay after extraction. There will be some probability of collision between the launch vehicle and platform because of airflow at higher dynamic pressure. The load point of the cargo parachutes for deceleration is the launch vehicle itself and/or hoisting attachment. The configuration for this type can be more complex because more parts are needed to separate platform and parachutes.

SRALT, MRALT, LRALT Raptor Type

This type will separate the launch vehicle soon before ignition. Cargo parachutes for deceleration are attached to the extraction platform. There will be low probability of collision between the launch vehicle and platform because the dynamic pressure at the time of separation will be low. The load point of cargo parachutes for deceleration is the platform. This configuration can be simpler because fewer parts are needed to separate platform and parachutes.

Hoisting Attachment Type

This type will unlash the launch vehicle when decelerating adequately at a distance far from the aircraft after extraction. Hoisting attachment will connect cargo parachutes. There will be low probability of collision between the platform and aircraft because platform will be separated far from the aircraft after extraction. There will be low probability of the collision between the launch vehicle and platform because platform will be separated after adequate deceleration at lower dynamic pressure. Load point of cargo parachutes for deceleration is hoisting attachment. Configuration can be more complex because more parts are needed to separate platform and parachutes.

The SRALT, MRALT, LRALT and Raptor method was selected and will be employed as the assembly, loading and separation method because of lower probability of collision and simpler configuration.

The authors developed a baseline extraction and deceleration system concept. A 15-foot parachute is employed as a pilot parachute to pull extraction parachute. A tow plate is the connection/separation instrument between the aircraft and line of pilot parachute. The extraction parachute is a 28-foot parachute, and an EFTC (Extraction Force Transfer Coupling) is the instrument to transfer extraction force by 28-foot parachute. Figure 3 shows a sketch of the extraction system. To decide on the design for the deceleration system, launch capability and terminal velocity of descent are considered. Figure 4 shows the sensitivity analysis results of number of cargo parachutes (G-11, 100-foot flat parachute). There is a small difference in launch capability between two through four parachutes. Thus, the nominal number of cargo parachutes is set to three.

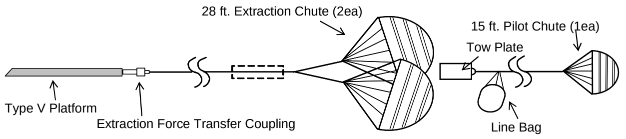


Fig. 3. Extraction System.

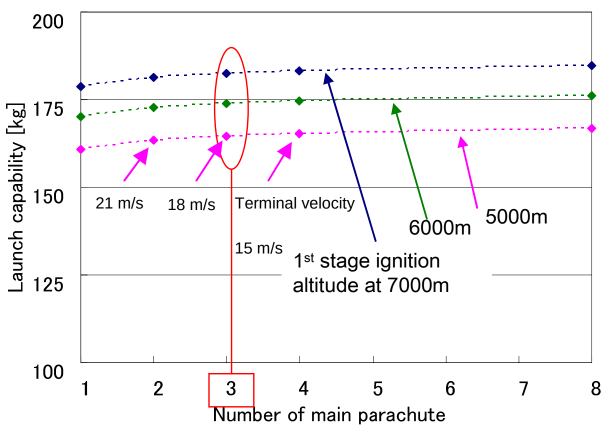


Fig. 4. Sensitivity Results for Cargo Parachute Number.

FIXATION METHOD SELECTION

The method of fixation has been considered referring to three types of existing methods for air drop system (shown in Table 3). The characteristics and merit/demerits of each type are shown below.

Mechanical Locks

This type will lock to the cradles by pins or some other mechanism. The cradles will be tied down on the platform by chains or some other mechanism.

This type will sustain load by pins in axial and upward direction, and by cradles in horizontal and downward direction. It will be easy to check using automated inspection equipment Existing platform can be readily purchased. It has been proven by another Japanese item.

Tie-down Belts

This type will tie a rocket down on the cradles by nylon belts or some other mechanism.

This type will sustain load by cradles in downward direction, by tie-down belts in axial, upward and horizontal direction. It will be difficult to check visually soon before drop because of difficult visual accessibility. Existing platform and drop equipment can be readily purchased. It has been demonstrated by U.S. bomb drops.

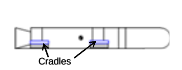
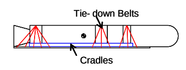
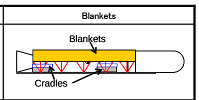
Blankets

This type will tie a rocket down on the cradles by fabric blankets and tie-down belts and ropes.

The upward load of this type can be lower compared to tie-down belts. This type will be difficult to check visually soon before drop because of difficult visual accessibility. Existing platform and drop equipment can be readily purchased, and COTS blankets are also available. It has been proven by U.S. target missile drops.

Mechanical locks have been selected and will be employed as fixation method because of easier handling.

Table 3. Fixation Method

Method	Mechanical Locks	Tie-down Belts	Blankets
Overview			
Characteristics	Will lock to the cradles by pin or some other mechanism. The cradles will be tied down on platform by chains or some other mechanism.	Will tie a rocket down on the cradles by nylon belts or some other mechanism.	Will tie a rocket down on the cradles by fabric blankets and tie-down belts and ropes.
Loading Condition	○ Will sustain load by pins in axial and upward direction, by cradles in horizontal and downward direction.	○ Will sustain load by cradles in downward direction, by tie-down belts in axial, upward and horizontal direction.	◎ Compared to tie-down belts, upward load can be lower.
Loading	○ Proven by another Japanese item.	○ Demonstrated by U.S. bomb drops.	○ Proven by the U.S. target missile drops.
Handling	◎ Easy to check using inspection equipment. Compatible with automatic checking.	△ Difficult to check visually soon before drop because of difficult visual accessibility.	△ Difficult to check visually soon before drop because of difficult visual accessibility.
Availability	○ Existing platform can be readily purchased.	○ Existing platform and drop equipment can be readily purchased.	○ Existing platform and drop equipment can be readily purchased. COTS blankets are also available.
Estimation	Mechanical Locks will be employed because of easier handling.		

◎: excellent, ○: good, △: poor

SEPARATION DELAY METHOD SELECTION

The method of separation delay has been considered referring to three types of existing methods for the air drop system (shown in Table 4). The characteristics and merit/demerits of each type are discussed below.

Off-board Command

This type will be separated by manual command after stabilization of attitude and rate. The command will be sent from the ground or chase aircraft.

Attitude at separation can be affected by turbulence during delay of telemetry data and command data.

This type needs antennas and receivers. If communication equipment on a rocket will be used, an electrical interface with the rocket will be needed, EMI (Electromagnetic Interference) with the airdrop aircraft must be avoided, and equipment must be in accordance with the radio law when command will be sent from chase aircraft.

Automatic Separation by Detecting Attitude and Rate

This type will be separated after detecting attitude stabilization by IMU/INS (Inertial Measurement Unit / Inertial Navigation System) on a rocket or IMU on the cradles.

There will be lower attitude error because of using the detected attitude and velocity.

This type needs an IMU. If IMU on a rocket will be used, an electrical interface with the rocket will be needed, EMI with the airdrop aircraft must be avoided, and equipment must be in accordance with the radio law to communicate with a rocket.

Timer

This type will be separated by timer decided by simulation.

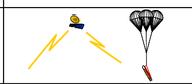
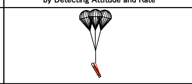
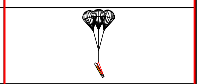
Attitude at separation can be affected by turbulence.

This type will be simpler configuration because the timer will operate independently, can be loaded on CES and can be achieved by employing existing products or modified products.

Timer has been selected and will be employed as separation delay method because of easier configuration.

The results of the extraction and deceleration analysis are documented in Ref. 3. Turbulence including gust will be taken into consideration on the deceleration analysis. On the basis of the analysis, timer method will be evaluated.

Table 4. Separation Delay Method

Method	Off-board Command	Automatic Separation by Detecting Attitude and Rate	Timer
Overview			
Characteristics	Will be separated by manual command after stabilization of attitude and rate. The command will be sent from the ground or chase aircraft.	Will be separated after detecting attitude stabilization by IMU/INS on a rocket or IMU on the cradles.	Will be separated by timer decided by simulation.
Attitude at Separation	△ Can be affected by turbulence during delay of telemetry data and command data.	○ There will be lower attitude error because of using the detected attitude and velocity.	△ Can be affected by turbulence.
Configuration	△ Need antennas and receivers. If communication equipment on a rocket will be used, electrical interface with the rocket will be needed.	△ Need IMU. If IMU on a rocket will be used, electrical interface with the rocket will be needed.	◎ Will be simpler configuration because the timer will operate independently.
Loading	△ EMI with the airdrop aircraft must be avoided.	△ EMI with the airdrop aircraft must be avoided.	◎ Can be loaded on CES.
Availability	△ Equipment must be in accordance with the radio law when command will be sent from chase aircraft.	△ Equipment must be in accordance with the radio law to communicate with a rocket.	◎ Can be achieved by employing existing products or modified products.
Estimation	Timer will be employed because of easier configuration.		

◎: excellent, ○: good, △: poor

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 DTA from the CES. The baseline drop test scenario is planned to be conducted at an altitude of 7,000 meters (23,000 feet), if possible. An overview of the drop test sequence is shown in Figure 5. 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.

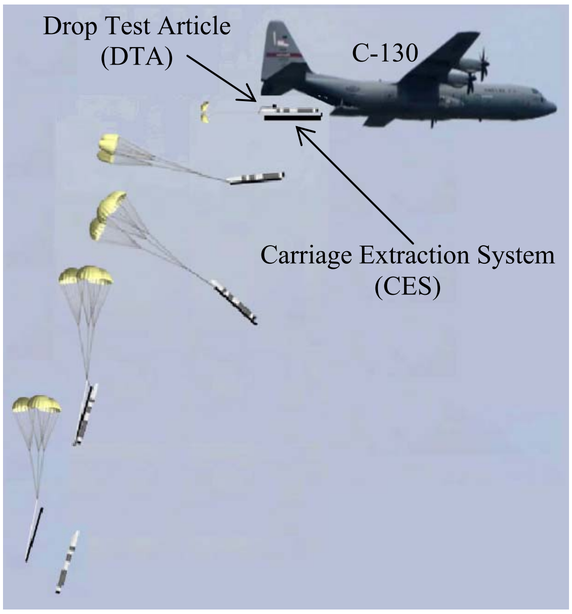


Fig. 5. ALSET Drop Test Overview.

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 5.

Table 5. 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 6. 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.

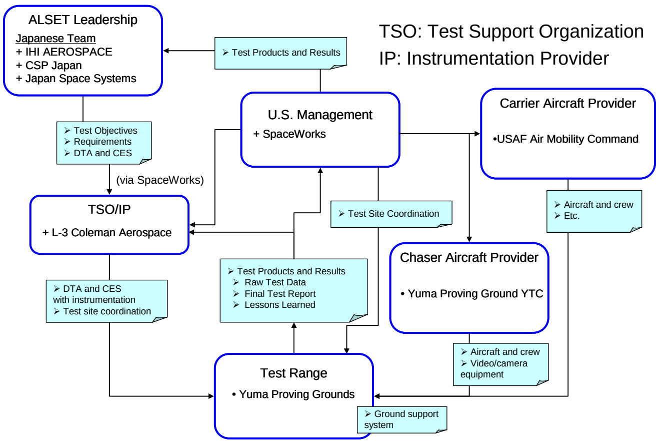


Fig. 6. ALSET Drop Test Organizations and Responsibilities

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 preliminary trade studies, the SRALT type air drop method was chosen due to aircraft availability and minimal aircraft modification needed, mechanical lock type fixation method was chosen due to easier handling, and timer type separation delay method was chosen due to easier configuration. For the ALSET project, a full-scale mass simulator air drop test is planned to demonstrate utilizing air launch for a future, operational space access system.

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, Coleman Aerospace assisted with the system requirements and definition phase by completing a conceptual 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. Rick Anderson, Program Manager for the activities at L-3 Coleman Aerospace.

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