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A REVIEW OF THE NEW GENERATION OF SMALL LAUNCH VEHICLE DEVELOPED BY CALT

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In recent years, there have been sustained demands for small satellites, both within the telecommunication sector and for scientific missions and those related to Earth observation. Cost-effective operations, affordable and reliable space access are important parts of the space transportation system of small satellites. According to the market-oriented needs, new generation of small launch vehicles indicate the wide range of potential application for small satellites. China Academy of Launch Vehicle Technology (CALT) small launch vehicle program efforts are underway to design, test, and develop technologies for small launch systems that mainly satisfy commercial needs at acceptable recurring costs. Significant progress has been made in undertaking the technical challenges of small launch systems and the accompanying management and operational approaches for achieving a low-cost program. This paper reviews the current status of the small launch vehicle program undertaken by CALT. It addresses the specific technologies and business issues being applied and proposed related to these two types of small launch vehicles. This paper also contains the technical and operability of CALT small launch vehicles including carrying capacity、trajectory design、cost analysis and estimation etc. to provide references for the small satellites market

I. INTRODUCTION

China Academy of Launch Vehicle CALT is a subsidiary of China Aerospace Science and Technology Corporation. It is the 1st and largest entity in China for research, design, manufacture, test and integration of Long March launch vehicle series. Due to the open market policy and grateful demanding for small satellite launching services. CALT is developing a new type of small launch vehicle, named Naga-1, which inherit the successfully experience and design of China ‘Golden Launch vehicle series’ LM-3, to provide low-cost, high-frequency launch capability for the rapidly and critically under-severed small satellite industry.

The developing of Naga-1 will deliver game changing costs, accessibility and reliability for the custom in domestic china and all over the world.

Fig. 1: Profile of NAGA-1

II. NAGA-1 OVERVIEW

Naga-1 is a two stage launch vehicle capable of delivering small satellite payload to LEO and SSO. Naga-1 is 29.219m long with lift-mass of 98.227 tones and uses a fairing that is 5.279 m long with a diameter of 3m. It uses Cryogenic and environment-friendly propellant. An YF-100 engine is installed on 1st stage and a YF-75 engine is installed on the 2nd stage. The approximate total cost of Naga is about $ 10,000,000.

	Unit	First Stage	Second Stage
Mass of Propellant	kg	77000	10498
Mass of structure	kg	6940	2685
Mass of fairing	kg	500	
Mass of payload	kg	820	
Lift-off Mass		98227.4	
Engine Designation	/	YF-100	YF-75
Propellant	/	LOX/ Kerosene	LOX/LH2
Ground Thrust	kN	1200	83.265
Ground Specific Impulse	m/s	2942.0	4295.2
Diameter	m	3.35	3

Table 1 General technical parameter for Naga-1

III. NAGA-1 DESCRIPTION

Naga-1 launch vehicle consists of the following major subsystems: vehicle structure, propulsion system, and control system, measurement system (telemetry system and tacking range safety system), propellant management system, separation system and auxiliary system.

III.I Vehicle structure

The function of the vehicle structure is to withstand the internal and external loads on the launch vehicle during ground transportation, hoisting and flight, in addition to housing all the subsystems. The vehicle structure comprises the first stage, second stage and payload firing.

The first stage includes inter-stage section, oxidizer tank, inter-tank section, fuel tank, rear transit section, tail section, engine, valve and pipes.

The second stage includes the Payload Adapter (PLA), vehicle equipment bay (VEB), cryogenic propellant common bottom tank and engine. The PLA mates the satellite with the Naga-1 and transfer the loads between them. The PLA can be one of the international standard interfaces designated as 660, 937B, 1194, 1194A and other tailored interfaces for small satellites and cub-sat due to the customs demands.

The payload fairing consists of the dome, forward cone section, cylindrical section and fairing separation mechanisms.

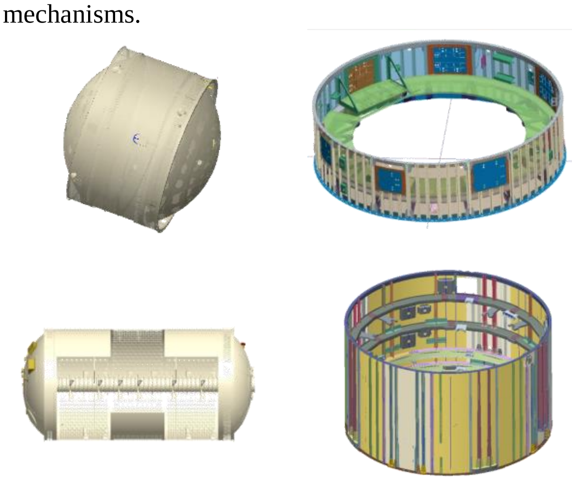


Fig 2: Structure illustration

III.II Propulsion system

The propulsion system, which consists of the engines and pressurization system, generates the flight thrust and vehicle control force.

In the first stage, a cryogenic and environment friendly propellant engine YF-100 is installed, of which can swing in both lateral and longitudinal direction to control pitch and yaw. The propellant tanks are pressurized by self-generated pressurization system. Auxiliary power is used to control roll. The propellant for YF-100 is liquid-oxygen and RP-1

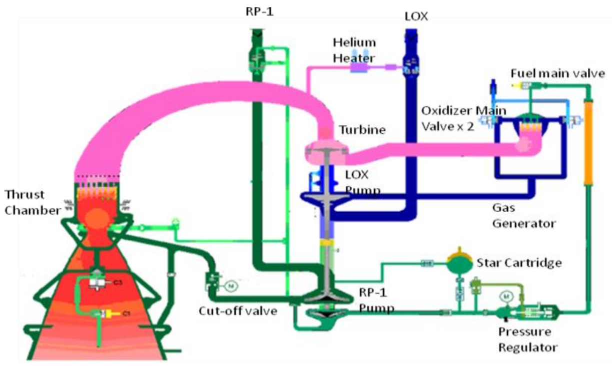


Fig 3: Working principle of YF-100

In the second stage, another cryogenic and environment friendly propellant engine YF-75 is installed, of which can swing in both lateral and longitudinal direction to control pitch and yaw. Auxiliary power is used to control roll. The propellants for YF-75 are liquid-oxygen and liquid hydrogen to provide higher impulse. The liquid hydrogen tank is pressurized with helium by autogenous pressurization system, and the liquid oxygen is pressurized by self-generated pressurization system.

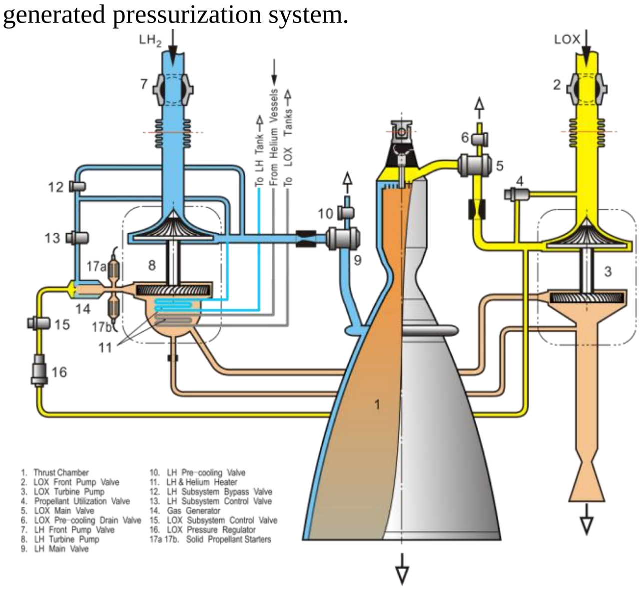


Fig 3: Working principle of YF-75

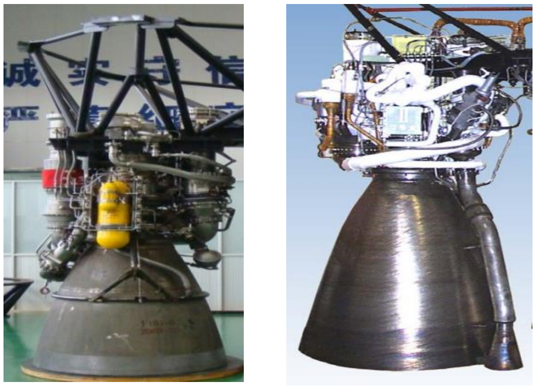


Fig 4: Profile of YF-100 and YF-75

III.III Control system

The function of control system is to maintain the flight stability, perform the navigation and guidance functions to deliver the satellite into the predetermined orbit. The control system uses an inertial platform and laser IMU, combined with computer-controlled guidance and digital attitude control. The control system uses advanced digital technology and redundancy design to provide enhanced reliability and flexibility for the missions.

III.IV Control system Measurement system

The measurement system includes the telemetry system and the tracking and range safety system.

The functions of telemetry system are to measure and transmit parameters of the launch vehicle in flight. Some measured data can be processed in real time. The data acquisition and encoding units in the telemetry system are powered in group based on sensors' location. The measurements of the command signals are digitized. The powering and check-up are performed automatically. The on-board converters are intelligent.

In terms of the tracking and Range safety system, it measures the trajectory and final injection parameters, and provide safety assessment information.

III.V Separation system

Separation system is to unlock the connecting mechanism and separate the connected sections. For Naga-1, three separations take place in sequence during the flight phase, i.e. first/second stage separation, fairing jettisoning, and SC/LV separation.

For the first/second stage separation, it uses the 'cold separation' theory. The explosive bolts are unlocked first and then the retro-rocket on the first stage rear section generates separation force and push the first stage away.

While for the fairing jettisoning, lateral explosive bolts are unlocked first and then follow by longitudinal explosive bolts, and finally the fairing turns outward around the hinges under the force of separation springs.

III.VI Separation system Auxiliary system

In addition to the main subsystem as mentioned above, there are auxiliary systems to perform necessary functions before launch vehicle lift-off, which includes measuring the propellant level and temperature, air conditioning, water proofing and dehumidifying for payload fairing.

IV. LAUNCH MISSION OF NAGA-1

Naga-1 launch vehicle is primarily used for LEO/SSO mission, and GTO mission can be conducted by adding a solid orbital raiser (Standard interface have been reserved for the function expanding). Naga-1 can be used to inject satellite into low orbit (LEO), which refers to orbits with average altitude lower than 2,000 km. Naga-1 can also be used to inject satellite into sun synchronous orbit (SSO), which refers to an orbit that maintains fixed angle with respect to the sun direction. That is, the orbital plane has a fixed orientation with respect to the earth-sun direction and the angle between the orbital plane and the earth – sun direction is constant. Four launch set have been chosen preliminary to analyse the launch capability for Naga-1 Launch Vehicle. The information of the four launch sites are listed in Table 2.

Launch Site	Longitude(°)	Latitude(°)	Altitude (m)
China	100.316	41.118	1067.1
Indonesia	136.4	-1.5	10
Sweden	21.1	67.9	380
Tanzania	39.6	6.3	10.0

Table 2 Information of preliminary launch site for Naga-1

IV.I Launch mission in JiuQuan Launch center (China)

In JiuQuan Launch centre in China, Naga-1 has the capability of injecting a satellite directly into a Sun-Synchronous Orbit. The launch performance of Naga-1 for a Sun-Synchronous Orbit mission is shown in Figure 5.

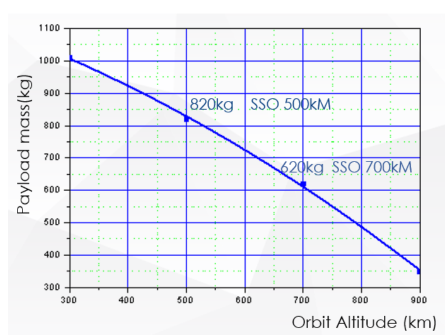


Fig 5: LEO Capability in china

IV.II Launch mission in Indonesia

The launch capability of Naga-1 for LEO mission at Indonesia is shown in Figure 6. Also, the theoretical Impact area is expressed in Figure 7. The First stage and the fairing are impacted in the Indonesia Ocean in the safety range.

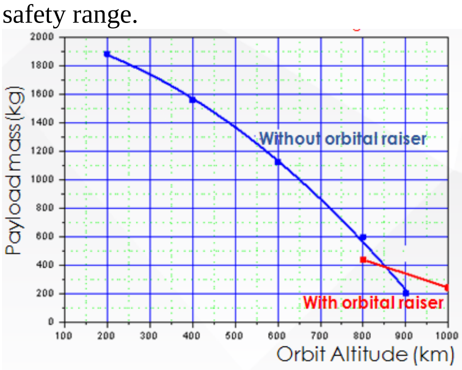


Fig 6: Naga-1 LEO Capability at Indonesia

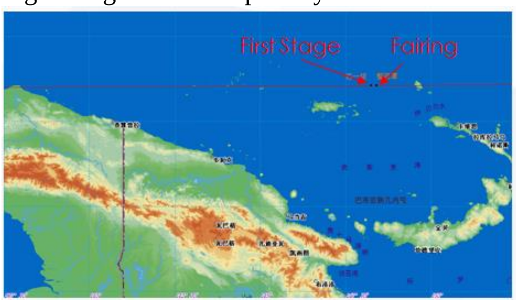
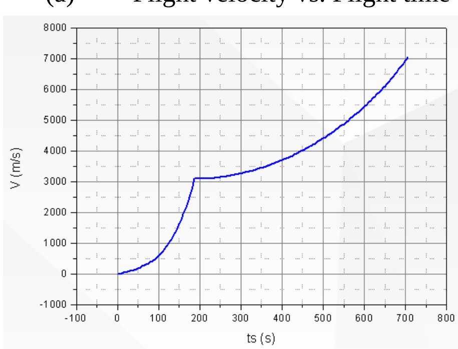


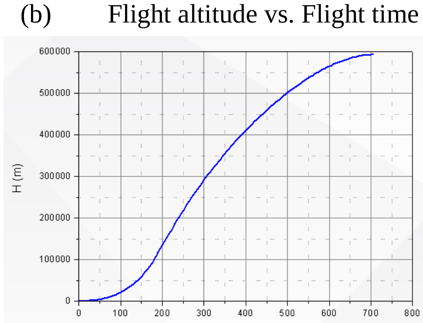
Fig 7: Theoretical Impact area

Also, Figure 8 shows the flight acceleration, velocity, March number and altitude vs. time.

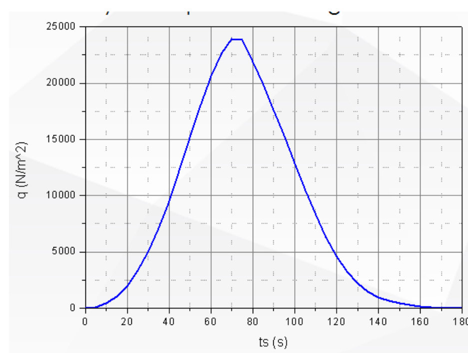
(a) Flight velocity vs. Flight time



(b) Flight altitude vs. Flight time



(c) Dynamic pressure vs. Flight time



（d） Longitudinal Load factor vs. Flight time

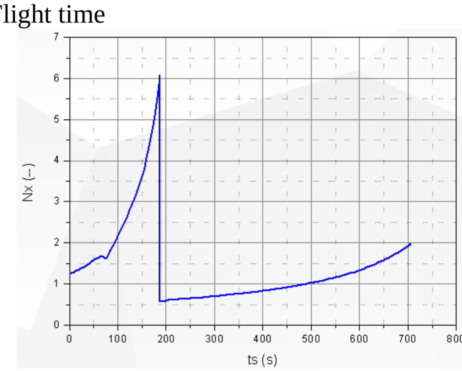


Fig 7: Flight acceleration, velocity, March number and altitude vs. time

IV.III Launch mission in Sweden

In Esrange launch centre in Sweden, Naga-1 has the capability of injecting a satellite directly into a Sun-Synchronous Orbit. The launch performance of Naga-1 for a Sun-Synchronous Orbit mission is shown in Figure 8.

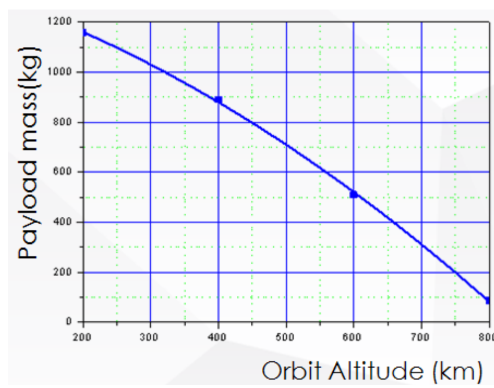


Fig 8: Naga-1 LEO Capability in Sweden

The Naga-L separation sequences for 600km SSO can be seen in Table 3.

	Time(s)	Action
a)	0.00	Liftoff
b)	10.00	Pitch over
c)	187.06	Stage-1 engine shutdown, stage-1 and stage-2 separation
d)	187.06	Stage-2 engine Ignition
e)	722.38	Stage-2 engine shutdown, SC/LV Separation

Table 3: Naga-L separation sequences for 600km SSO

IV.IV Launch mission in Tanzania

While for the launch mission at Tanzania, the launch capability of Naga-1 at LEO 400km is about 1545kg, at LEO 600km is about 1095kg, at LEO 800km is about 595 kg, while for the LEO 900km, is decreases to 195kg. Also, Table 4 shows the theoretical Impact Area of Naga-1.

	Impact Longitude(°)	Impact Latitude(°)	Impact Altitude (km)
First Stage	51.508	6.098	1317
Fairing	51.669	6.093	1334

Table 4: Theoretical Impact Area (600km LEO)

V. MISSION INTEGRATION AND MANAGEMENT

Currently, NAGA-1 is still under development with an expectation to achieve the maiden flight in two years. To make the NAGA-1 more market-oriented and competitive in the market, we would like to joint force in technical research, management and operation, in the meanwhile, we are also explore the potential cooperation in advanced manufacturing, launching, testing and measurement.

Each Naga-1 Mission will follow a typical timeline; a typical mission will take within one week to achieve the launching mission.