

EUROPEAN SPACE AGENCY
CONTRACT REPORT

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Executive Summary
to Contract number 20342/06/F/VS
Study of European Privately-Funded
Vehicles for Commercial Human Space Flight

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Table of Contents

1	Introduction	3
1.1	Scope	3
1.2	Background	3
2	Customer survey	4
3	Customer experience	6
4	Vehicle configuration	7
4.1	STARCHASER 5 booster specification	7
5	Technology test bed – SKYBOLT	9
5.1	SKYBOLT specifications	9
6	THUNDERSTAR capsule	10
7	Launch Escape System (LES)	12
8	Operations and ground infrastructure	13
9	Risk evaluation	14
10	Conclusions	15

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

1 Introduction

1.1 Scope

This is the Final Report under ESA Contract number 20342/06/F/VS, and has been prepared by Starchaser Industries Ltd. The work has been funded by ESA's General Studies Programme.

1.2 Background

Starchaser Industries is working on two concepts for the purpose of exploiting the nascent space tourism market. The near term objective is the creation of a reusable space capsule called Thunderstar which will be used for sub-orbital flights in excess of 100km. The second system is a vertically launched 8 seat sub-orbital space plane that could potentially be upgradeable for orbital applications.

This document will focus upon an analysis of the development and operation of the near term Thunderstar capsule concept.

The Thunderstar capsule design features a Nitrogen/Oxygen pressurised environment to 75 KPa where the occupants will be further protected from the hostile environment of space by means of Russian Sokol derived spacesuits. The spacecraft will also be fitted with a Launch Escape System (LES) taking the form of a tower system similar to that used for Mercury, Apollo and Soyuz spacecraft. A Starchaser 5 launch vehicle will be used to launch the Thunderstar capsule.

All critical systems will be automated and protected by redundant back up systems. Taking the above safety features into account, the survivability from a catastrophic failure of the launcher hardware is considered close to 100%.

The planned frequency of flight for any given capsule will be about once per week with a typical mission duration in the order of about 20 minutes. The fully automatic capsule will employ a single pilot.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

2 Customer survey

Starchaser conducted an online survey in order to gather data about what potential customers might be looking for in terms of a sub-orbital spaceflight experience. Data from this survey was evaluated and placed into context together with relevant results obtained from the following historical studies;

- Space Tourism Market Study by Futron Corporation 2002
- “Filling in some gaps” – Executive Summary of The Adventurer’s Survey of Public Space Travel by Derek Webber of Spaceport Associates and Jane Reifert of incredible Adventures 2006
- MBA Dissertation “Establishing a Low Cost Sub-Orbital Space Business in the UK” by Mark Morley 2006

Feedback from the survey was generally in agreement with data from previous surveys and to a large extent, the results support the proposed Starchaser spaceflight model. Moreover, the Starchaser survey provided additional useful data that will be used to more closely define the Starchaser spaceflight experience to better meet customer requirements.

It seemed to be accepted by most respondents that a training period would be required and that the preferred duration should be about two weeks. All the main points of the Starchaser astronaut training syllabus could be completed inside of this time frame with the exception of the Free Fall (AFF) parachute course. Starchaser will therefore revisit this area with a view to the possibility of reducing the AFF requirements.

By far the biggest challenge to making space tourism an every day occurrence seems to be the issue of safety. In addition to protecting the lives of passengers and crew it is vital that public perception begins to view this new industry as safe. Starchaser can assure passenger safety through the inclusion of a Launch Escape System and can maintain a perception of safety by publicly promoting its untarnished and successful track record.

The use of Starchaser spacesuits bring in an added layer of safety and the results of the survey indicate that potential space tourists would be willing to and expect to wear them.

The ability to leave the seat and move around the cabin during weightlessness although currently a unique selling point for Virgin Galactic, does not necessarily seem to be a deciding factor for most potential space tourists, who would probably reject this feature in favour of a safer overall flight experience.

It would seem that partaking in the adventure of a lifetime and seeing the Earth from space would be the highlights for most space tourists

This study has also indicated that although vertical ascent would be acceptable to many, horizontal landing seems to be the preferred method for return to Earth. This

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

will be achieved by attaching a steerable ram air parachute canopy to the Thunderstar capsule together with wheeled landing gear.

Next to safety, the issue of pricing seems to be of highest importance. Average earnings within the UK are equal to £477 per week or £23k per year with an upper limit of £46k per year. A willingness to pay three months salary, even at the upper limit, would therefore only equate to a preferred ticket price of around £12k per flight. Previous surveys have shown that early adopters would be willing to pay far more per flight, Virgin Galactic for example are selling seats at around £100k, but this still likely represents less than 3 months salary for the individuals concerned. The less expensive the flight therefore, the greater the demand will be expected to be.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

3 Customer experience

The Thunderstar / Starchaser 5 reusable launch vehicle has been designed to provide a unique personal spaceflight experience unlike anything offered by any of the other leading space tourism operators.

Although the initial spacecraft concept envisioned a 3 person crew comprising of one pilot astronaut and 2 passengers, cash flow analysis has shown that a larger capsule able to accommodate one pilot and up to 4 passengers may be required.

The Starchaser Space Tourism package will include a two week training course (incorporating medical and physical examinations), the provision of an IVA pressure suit and the launch experience itself.

Starchaser space tourists will be seated on their “backs” in the +G X orientation and will be firmly secured into their seats by means of a safety harness. The Starchaser Pilot is included more for the safety of the passengers than for the purpose of any real flying as all systems will be fully automatic.

Thunderstar crew compliment will be a maximum of 5; made up from a single pilot and up to 4 fare paying passengers.

Peak accelerative forces during the boost phase of the flight will be around 4.5 G and the powered flight will last for about 80 seconds where the vehicle will be travelling at a velocity of 4,615 kilometres per hour (3289 mph). The capsule will then be separated from the booster by means of a Launch Escape System firing before entering the coast phase of the flight profile where the decelerating capsule will reach an apogee in excess of 100 km.

Starchaser’s space tourists will experience about 3 minutes of microgravity, see the curvature of the earth and the blackness of space. They will experience everything the first American astronauts experienced before returning safely to the Earth via parachute recovery of the capsule. The reusable booster and Launch Escape System will also be recovered for subsequent re-use via parachute.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

4 Vehicle configuration

Starchaser has chosen a simple ballistic rocket for its initial Space Tourism applications as opposed to a more complicated winged vehicle approach. The ballistic concept offers several key advantages in that it is less expensive, is simpler to build and certify, and such a design more readily lends itself to the incorporation of a Launch Escape System which provides an additional level of safety.

Initially a HTPB liquid oxygen hybrid rocket system was investigated as a candidate propulsion choice for the Starchaser 5 booster but after significant Research & Development, Starchaser's efforts switched to focus upon a more traditional liquid oxygen / kerosene bipropellant series of engines.

Starchaser's liquid rocket programme included the manufacture and test of Churchill Mk 1, Churchill Mk 2 and Churchill Mk3, with respective thrust performance of 4,905 Newtons, 29,430 Newtons and 147,150 Newtons. Prior to a test firing of the Churchill Mk 3 however, development of a "mid -sized" engine with thrust of 68,670 Newtons was initiated under the "Storm" banner.

A cluster of four Storm engines will be needed in order to propel the Thunderstar / Starchaser 5 vehicle into space.

Storm can also be used to propel Starchaser's Skybolt liquid propellant sounding rocket into space. Effectively a scale model of the Starchaser 5 vehicle, Skybolt is being developed as an engineering test bed that also has the potential to find application as a low acceleration, reusable sounding rocket. All of Starchaser's liquid propulsion systems to date have been pressure fed though it is accepted that there will be significant performance advantages to changing to a pump fed system.

At the time of writing the specifications of the Thunderstar / Starchaser 5 vehicle are as follows;

4.1 STARCHASER 5 booster specification

Propellants	Liquid
Fuel	Kerosene
Oxidiser	Liquid Oxygen (LOX)
Thrust (sea level)	274,680 Newtons (28000Kg)
Chamber pressure	20.7 Bar (300psi)
Mixture ratio	2.205:1
Specific impulse (sea level)	230 seconds
Real nozzle correction	0.9425
Propellant mass flow	129.17 Kg/sec (maximum)
Kerosene	40.30 Kg/sec (maximum)
LOX	88.87 KG/sec (maximum)
Burn time (in flight)	75 seconds (nominal); 88 seconds (extended)
Total burn time	77 seconds (nominal); 88 seconds (extended) <i>(note: extended burn (+9 seconds) possible with current design if</i>

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

	<i>required)</i>
Extra propellant	2 seconds for hold down on pad (kerosene & LOX) 2 seconds kerosene for safe burnout at altitude
Total propellant	10026.7 KG (nominal); 11447.6 Kg (extended)
Kerosene	3183.7 Kg (nominal); 3627.4 Kg (extended)
LOX	6843.0 Kg (nominal); 7820.6 Kg (extended)
Total flight propellant	9768.4 Kg (nominal); 11189.2 Kg (extended)
Kerosene	3103.1 Kg (nominal); 3546.4 Kg (extended)
LOX	6665.3 Kg (nominal); 7642.8 Kg (extended)
Feed system	Pressure fed
Pressurant gas	Helium
Cooling method	Regenerative & film cooling

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

5 Technology test bed – SKYBOLT

Starchaser Industries Ltd is currently constructing a new sounding rocket named 'Skybolt'. This rocket is designed to carry a 20 Kg payload to over 100 Km, and will be the company's first space-shot. Work on the engine and control systems and the overall design is nearing completion. The propulsion system for this new rocket has been designated "STORM" and is capable of producing 68,670 Newtons (7000 Kgf) of thrust.

The Skybolt rocket has a planned launch location in New Mexico from the up and coming Spaceport America that is being constructed close to the White Sands Missile Range (WSMR).

5.1 SKYBOLT specifications

Propellants	Liquid
Fuel	Kerosene
Oxidiser	Liquid Oxygen (LOX)
Thrust (sea level)	68670 Newtons (7000 Kgf)
Chamber pressure	20.7 Bar (300psi)
Mixture ratio	2.205:1
Specific impulse (sea level)	230 seconds
Real nozzle correction	0.9425
Propellant mass flow	32.29 Kg/sec (maximum)
 Kerosene	10.07 Kg/sec (maximum)
 LOX	22.22 KG/sec (maximum)
Burn time (in flight)	42 seconds (nominal); 47 seconds (extended)
Total burn time	44 seconds (nominal); 49 seconds (extended) <i>(note: extended burn (+5 seconds) possible with current design if required)</i>
Extra propellant	2 seconds for hold down on pad (kerosene & LOX) 2 seconds kerosene for safe burnout at altitude
Total propellant	1440.9 KG (nominal); 1602.4 Kg (extended)
 Kerosene	463.3 Kg (nominal); 513.7 Kg (extended)
 LOX	977.6 Kg (nominal); 1088.7 Kg (extended)
Total flight propellant	1376.3 Kg (nominal); 1537.8 Kg (extended)
 Kerosene	443.2 Kg (nominal); 493.6 Kg (extended)
 LOX	933.1 Kg (nominal); 1044.2Kg (extended)
Feed system	Pressure fed
Pressurant gas	Helium
Cooling method	Regenerative & film cooling

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

6 THUNDERSTAR capsule

The Thunderstar capsule has been designed as a ballistic re-entry capsule to be carried aloft by the Starchaser 5 booster to an altitude in excess of 100 Km for sub-orbital flights. The capsule development has gone through a number of design reviews in order to arrive at an optimum configuration for safety, reliability, cost effectiveness and overall customer experience.

The final design for the THUNDERSTAR capsule includes:

A Structure consisting of the following:

- 1) A shaped pressure hull designed to hold a nitrogen / oxygen environment at up to 1 atmosphere pressure for the crew to breathe.
- 2) An outer structure of ribs and stringers to support the delicate pressure hull and also to transmit the flight loads evenly through to the pressure hull so as to not cause it damage. The outer hull will also act as a good insulating layer and provide room for wiring looms and gas piping that need to be run around the vehicle for the various systems
- 3) A Heat Shield (Material to be determined). For now the heat shield has been modelled around a stainless steel dish, which can be coated with a heat resistant material if required.

A Life Support System consisting of:

- 1) An adequate gas storage facility for the distribution of enough breathable air for the duration of the mission. (Total expected sealed environment to be 2 hours)
- 2) An air purification system to remove excess carbon dioxide and filter / re-circulate the air so it is maintained at acceptable levels for the crew to breathe comfortably.
- 3) Separate life support kits for the crew, who will be wearing space suits as a backup should the main cabin lose pressure.

A Reaction Control System (RCS) consisting of:

- 1) Propellant storage tanks to hold enough propellant for the expected duration of RCS use.
- 2) Thrusters to give control of Pitch, Yaw and Roll of the vehicle
- 3) Additional plumbing that will be required to operate the system.
- 4) A computer controlled flight system (linking into the navigational system information) which can automatically perform the RCS manoeuvres without the pilot
- 5) Suitable displays and controls (overrides) for the pilot to operate the system

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

manually should the computer control malfunction.

A Navigational System consisting of:

- 1) An inertial package consisting of the required number of gyroscopes, accelerometers, or GPS devices to accurately measure the spacecrafts position and orientation.
- 2) Suitable Displays for the pilot for all the above information

A Recovery System consisting of:

- 1) A parachute recovery system to slow the vehicle down to acceptable landing speed to bring the crew safely back down to Earth.
- 2) Landing Airbags to further cushion the impact with the ground.

A Telemetry and Communications System consisting of:

- 1) All radio systems required to communicate with the ground, including voice, video and data streams from the vehicle.
- 2) Black-box type data recorder(s) for data recovery should a serious accident occur.
- 3) Visual displays for the pilot on relevant information, e.g. rocket engine status displays.
- 4) Backup data recording devices.

Additional Electrical Equipment consisting of:

- 1) A suitable power source to run all the above equipment.
- 2) A suitable backup power source.
- 3) All additional electrical equipment that doesn't fall within the above categories but will be needed for other functions e.g. lighting.

A pilot control console consisting of:

- 1) Suitable displays for all essential flight information.
- 2) An ergonomically designed display that is easy to use.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

7 Launch Escape System (LES)

The Thunderstar Launch Escape System (LES) will be powered by means of a hybrid propellant rocket utilising a liquid Hydrogen Peroxide oxidiser together with Hydroxyl-Terminated Polybutadiene (HTPB) fuel grains. The LES rocket is capable of producing 58,860 Newtons (6000 Kg) of thrust for 8.25 seconds duration, which is capable of pulling the Thunderstar capsule (weighing 1097 Kg) to a safe recovery altitude, even from a ground abort scenario.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

8 Operations and ground infrastructure

The following is a list of the equipment that is anticipated to be required for launch operations. Details for each piece of equipment are given where known.

1. Launch Release Clamps / Mechanism – 4 off, used for a single launch. Each designed to hold down a maximum force of 98,100 Newtons.
2. Kerosene (Jet-A1) Storage Tanks – A bunded kerosene store will be located at a safe distance from the launch pad. The kerosene would then be transferred to the rocket by means of fixed pipes or mobile bowser units. This storage capacity should be at least 9,000 litres.
3. Liquid Oxygen (LOX) Storage Tanks – As with the kerosene storage tanks, a similar bunded tank system will be required for the oxidiser. This storage capacity should be of the order of 14,000 litres capacity.
4. Hydrogen Peroxide (HTP) Production & Storage Area of 500 litres.
5. Compressed Gas Storage Area –
 - a. Compressed Air – 4,031 Nominal litres
 - b. Nitrogen – 27,155 Nominal Litres
 - c. Helium – 1.1 million Nominal Litres
6. Compressor System to fully charge all pressurised vessels to levels above those that are normally supplied by Starchaser's gas suppliers
7. Water Storage & Fire Fighting – a large quantity of water should be supplied directly to the launch pad for use in the acoustic suppression system. The exact quantity of this water to be passed under the rocket as it ignites is not known at the time of writing. A small water storage tank will be mounted on the top of the launch tower to act as a fire fighting system and also to provide a water supply for the launch pad engineers who will be loading the HTP into the LES rocket for safety purposes. A larger ground based water supply can be used for fire fighting at the base of the launch pad, which is the most likely place for a fire to start. This could also be provided by standard mobile fire fighting units.
8. Power Requirements – The exact power requirements are not known at the time of writing. The equipment that will require the most power is the compressor system which will be 3 phase. A series of backup generators can be put in place to provide the UPS (Uninterrupted Power Supply) to all critical systems.
9. Propellant Transfer Equipment – transfer equipment will be required in order to move the stored propellant to the rocket vehicle. This will be accomplished either by transfer lines and pumps, or mobile bowsers.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

9 Risk evaluation

Risk assessment implications are those arising from the launch of a large vehicle travelling at high velocity and containing a number of flammable propellants. Risks arise from excessive levels of noise, potential for explosion or release of corrosive / toxic substances, failure of highly pressurised components and generation of high velocity projectiles, spent vehicle components falling from high altitudes onto assets or personnel / members of the public and high temperatures from the vehicle exhaust.

The trajectory of the vehicle and the guidance control will be selected to maximise altitude and minimise down range travel. The launch azimuth will be selected to keep the vehicle as close to the centreline of the range area as possible.

A detailed risk and hazard assessment will be developed which will identify all potential risks to Starchaser operational staff and crew, range staff, members of the public and protected assets. This will include potential risks to the environment. There is no current legislation in the space tourism area, so until this point, the risk and hazard assessment has been produced in accordance with the requirements of the launch range Flight Safety Code. The assessment demonstrates that all potential risks have been identified, their consequences determined and that the risks are As Low As Reasonably Practicable (ALARP).

Occupational health and safety during site operations will be overseen by Starchaser's Health and Safety Coordinator. All propellant / pressurised components will be overseen by Starchaser's propulsion specialists with the cooperation of the representatives of the supply companies where appropriate. Safety during operation of the vehicle will be controlled by the mission control team. Final authority over operations will rest on the approval of the Range Safety Officer.

The overall management of safety for the flight programme at the range will be covered in a Safety and Operations Plan which will detail the arrangements for ensuring safe operations throughout the flight programme and will include details of the safety organisation and specific roles and responsibilities.

An Emergency Response Plan will also be developed which will define the procedures, responsibilities and actions to be taken should an emergency situation arise. The Risk and Hazard Assessment and both the Safety Operations and Emergency Response Plans will be submitted as part of the range licensing processes.

Document reference:	R071105
Issue:	Draft A
Date:	5 th November 2007

10 Conclusions

The work which has been summarised in this report has hopefully proven that the proposed designs for the Company's Starchaser Space Tourism Vehicle is technically sound. No major errors or significant design changes were required when the various parts of the vehicle were analysed / designed in more detail. The flight simulations using the correct mass budgets which were written for the various components proved that the rocket (specifically the Thunderstar Capsule) should be capable of reaching 100 Km to satisfy the altitude requirements for the mission. The various life support, attitude, recovery and backup systems which have been specified should allow the vehicle to be safely recovered and the crew to return safely to earth. These predictions have been further backed up by Finite Element Analysis and CFD work on the various parts of the vehicle.

One area of concern for the recurring costs of such a launch is the price and availability of large volumes of helium that will be required for the pressure fed system which is probably the only issue that could make this project unfeasible. An interesting question is posed with regards to which pressurising gas should be used.

A significant amount of work however needs to be undertaken in order to prove the pressure fed systems viability, which should be thoroughly tested on the Skybolt test vehicle prior to the later Starchaser 5 launches. By following the traditional Starchaser step by step approach the eventual Space Tourism rocket will offer far more confidence to both the flight crew and the ground crews who operate it, and should offer a unique experience to the customers who fly aboard it.

A number of key technologies have been identified that have yet to be developed or sourced at a cost that maintains the programmes commercial viability.

Initial costings have shown that a commercial case can be made, but to achieve the mass market levels, based on up to 3 month salary as a baseline for acceptability, significant cost savings per passenger need to be made that can only be achieved by developing a larger capsule with subsequent progression to a space plane design.