

SUBORBITAL RESEARCH ASSOCIATION

MISSIONS WITH THE LYNX

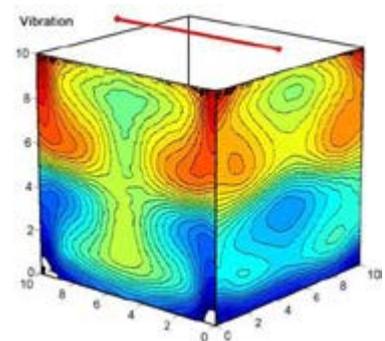


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1. INTRODUCTION

A group of Scientists involved in space research have created the Suborbital Research Association whose goals are to promote the suborbital scientific and technical research aboard suborbital platforms that will be available in the coming years ; to provide the necessary assistance to the practical realization of fundamental and applied scientific research in suborbital environment; and to promote scientific research in suborbital flights to the general public, youth and students.

The Association aims at gathering scientists and help them in accessing research opportunities in suborbital flights by considering the different suborbital platforms. For this, the Association will collect funds from institutional, industrial and private sponsors in order to allow the realization of selected experiments.

All fields of research on suborbital platforms are considered, from life and physical sciences in microgravity to astrophysics and atmospheric research, as well as tests of space technology in the broadest sense.

Currently, the only platforms enabling experiments involving humans as subjects of experiments or operators are aircraft parabolic flights or the International Space Station (ISS). Aircraft parabolic flights are limited by the microgravity time (20s) and the International Space Station is limited by the cost of experiments and the long preparation time. These two factors handicap research to be carried out by or on human beings. Therefore, new flight possibilities must be considered and offered to researchers. Moreover, it is also proposed to embark on every flight opportunity at least one experiment proposed by students, tomorrow's researchers.

Independently from official space agencies, American and European private sectors have embarked on the development of rockets and spacecraft to conduct experiments during suborbital flights in space.

Among the 20 private companies involved in the development of platforms for suborbital flights, three companies retain attention by their technical advances and the credibility of the access to space in the near future:

- *The Spaceship Company* (*Virgin Galactic* associated with *Scaled Composites*) ;
- *XCOR Aerospace* ;
- *Swiss Space Systems S3*.

The American company *The Spaceship Company* is developing the *SpaceShipTwo* spacecraft that will carry two pilots and six passengers at a cost of 250,000 USD from 2014 onwards.

The American company *XCOR Aerospace* develops the *Lynx* spacecraft, carrying a pilot and a passenger sitting both at the front of the aircraft at a cost of 95,000 USD from end of 2014 onwards.

The European company *Swiss Space Systems S3* is studying the concept of a shuttle, the *SOAR*, that will launch satellites and take passengers from 2017 onwards for an yet unspecified cost.

In view of the preparation and progress of development of the various projects and the possibility to embark scientific experiments detailed more below, it appears that the *XCOR Aerospace* company with its *Lynx* spaceship seems to be the best choice to perform a first series of suborbital flights for scientific and technical experiments from end of 2014, with the following advantages:

- low cost (95,000 USD or approx. 75,000 €per flight)
- within short delays (a few months to one year)
- possibility to board several biomedical and physical sciences experiments
- possibility to conduct other types of experiments in the upper atmosphere.



In the following sections, this document presents:

- the environment of weightlessness and suborbital flights in general (Section 2),
- a comparison of the three platforms by *The Spaceship Company*, *XCOR Aerospace* and *Swiss Space Systems S3* (Section 3),
- more detailed possibilities of the spaceplane *Lynx* from *XCOR Aerospace* (Section 4),
- a comparison of the various platforms for microgravity research (Section 5),
- the advantages of suborbital flights compared to other platforms (Section 6),
- examples of first scientific and technical experiments that could be performed (Section 7),
- opportunities for student experiments (Section 8).

2. WEIGHTLESSNESS AND SUBORBITAL FLIGHTS

Weightlessness, or absence of gravity effects, is the new environment that today's astronauts have to face and that tomorrow travellers will have to get used to. With the advent of the International Space Station, this environment of weightlessness is the place where new scientific and technical research are conducted in which students take part as tomorrow's scientists.

Space technologies, already abundantly present in our everyday life, will be more prominent in tomorrow's society. From casting of new materials and alloys to the study of fluids without the constraint of their own weight, from adaptation of living systems, including humans, to biotechnology, with creation of new molecules for pharmaceutical use, the weightlessness environment enables new progress in scientific areas already under exploration and will enable new discoveries in areas still not currently suspected.

Weightlessness is the environment obtained in a vehicle which is subject to the sole force of gravitational attraction, in a state of free fall. Inside this vehicle in free fall, the gravitational attraction force is exactly balanced by inertial forces existing in the referential frame of the vehicle in free fall, weightiness and gravity effects are thus cancelled.

This ideal state is however hardly feasible in practice and small residual forces still exist, yielding a microgravity environment. This environment is attained aboard orbital space platforms, where Earth's gravitational force is balanced by inertial forces due to the orbital motion. This environment is also achieved on Earth in experimental automatic free falling platforms and aircraft-laboratory describing parabolic trajectories offering periods of microgravity of a few seconds used for short-term experiments.

Suborbital flights of sounding rockets and, in the near future, of spaceplanes offer a microgravity environment of several minutes suitable for other types of longer experiments. After the launch with accelerations of several g, the microgravity environment is obtained during the flight ballistic phase after engines have been turned off. No forces other than gravity act on the vehicle in free fall for several minutes, before landing back on ground.



3. COMPARISON OF THREE SUBORBITAL PLATFORMS

Several private companies are currently working on the development of suborbital vehicles that will take private astronauts and experiments in suborbital weightlessness.

Among the 20 or so private companies having space system development projects, only two are able to offer credible access to space in the near future, estimated to be between one and three years:

- *The Spaceship Company* (*Virgin Galactic* associated with *Scaled Composites*)
- *XCOR Aerospace*

The European company *Swiss Space Systems S3* is still at the stage of conceptual studies and does not foresee suborbital flights before 2017

3.1 Technical Aspects

The two companies *The Spaceship Company* and *XCOR Aerospace* have different technical approaches.

For *The Spaceship Company*, the *SpaceShipTwo* spaceship takes off attached to its carrier aircraft *WhiteKnightTwo* from a Space Port in New Mexico. At an altitude of 15,000 m, the *SpaceShipTwo* is jettisoned from the carrier aircraft and, powered by a hybrid rocket to more than Mach 3, climbs to an altitude of 110 km, where it describes a long parabola of 6 minutes before re-entering the atmosphere and landing like an airplane. The *SpaceShipTwo* carries two pilots and six passengers. The cabin is wide enough to allow passengers to float freely and to look through windows.

It could be possible for a private astronaut to take one or several small experiments into his suit pockets. It might also be possible for a private astronaut to embark experimental material taking another passenger place.

For *XCOR Aerospace*, the *Lynx* spaceship is a small spaceplane, which takes off like a normal aircraft from a space airport in the California Mojave desert, carrying a pilot and a passenger sitting both at the front of the spaceship. The spaceplane is powered by four rocket engines using liquid fuel to its apogee before returning to land as a glider. Three models are planned: *Mark I*, *Mark II* and *Mark III*. The first, *Mark I*, is planned to begin a series of test flights at the end of 2014 to Mach 2 at an altitude of 60-65 km. Based on the results of *Mark I*, the second, *Mark II*, would start its flights in 2015 at Mach 3 up to an altitude of 100 km. The third, *Mark III*, would follow in 2016. The cockpit of the *Lynx* is not wide enough to float freely. The passenger astronaut can carry small experimental equipment into his suit pockets. In addition, the cabin configuration is such that experiments can be installed behind the pilot's seat in the cockpit at the front of the spaceplane and activated by the passenger astronaut. Two canister compartments located at the rear of the spaceplane can also accommodate two small experiments. Finally, the *Mark III* spaceplane will carry a container on the top (Pod) for automatic or remotely controlled experiments or to launch satellites. Other technical details are given in the technical specifications of the *XCOR Aerospace Lynx*.

Table 1 presents some technical data of the systems proposed by these two companies.



TABLE 1: TECHNICAL DATA

	<i>SPACESHIP COMPANY (Virgin Galactic/Scaled Composite)</i>	<i>XCOR AEROSPACE</i>
Spaceship	<i>SpaceShipTwo</i> launched by <i>WhiteKnightTwo</i>	<i>Lynx</i> spaceplane; 2 models: <i>Mark I</i> and <i>II</i>
Cabin size	L: 3.66 m x diam: 2.28 m Possibility of free-float in weightlessness	Cockpit has 2 seats No free-float in weightlessness
Number of persons	2 pilots + 6 passengers	1 pilot + 1 passenger
Apogee	110 km	<i>Mark I</i> : 65 km <i>Mark II - III</i> : 100 km
Weightlessness duration	6 minutes	<i>Mark I</i> : 1 minute at $< 10^{-2}g$ <i>Mark II - III</i> : 3-4 min. at $< 10^{-2}g$
Max. speed	4 200 km/h	3 700 km/h (Mach 3)
Mass/volume available for experiment	No detailed information available	(1) Cabin: 20 kg Trapezoidal volume: Hxwxl: 50 x 40.5 x (46 - 10.3) cm ³ (2) 2 canisters in the back: 3 kg, L 20 cm x 15 cm diam (3) Container on roof (Pod): <i>Mark II</i> : 280 kg L: 240 cm x diam: 43 cm <i>Mark III</i> : 650 kg L: 340 cm x diam: 76 cm
Foreseen start of private flights	2014	<i>Mark I</i> : end of 2014 <i>Mark II</i> : 2015 <i>Mark III</i> : 2016

The European company *Swiss Space Systems S3* explores the concept of a space shuttle *SOAR* carried on top of an Airbus A300 certified for zero-g flight. The shuttle would use standard fuels, while his return to the ground after the suborbital flight will be as a glider, without using fuel. The *S3* company targets mainly the launch of small satellites in orbit, but also embarking an unspecified number of passengers and experiments for an unspecified cost. The *S3* company has as a partner the European Space Agency, Dassault Aviation, the Von Karman Institute, Louvain University, and several Belgian and Swiss companies. The company *S3* is currently completing a conceptual Phase A study, and foresees the first flights starting from 2017.

3.2 Financial Aspects

The company *Virgin Galactic* offered initially the possibility to reserve a space flight for a total amount of 200,000 USD (approx. 155,000 €), as a traveller (deposit: 10%) or pioneer (deposit: 50%) or founder (deposit: 75%) but due to the success of pre-bookings (more than 100 Millions of USD of down payments by more than 500 future participants), schedules of payments have been eliminated in light of already completed pre-sales. Since mid-2013, the price has increased to 250,000 USD. There are now two possibilities:

- prepayment of the total of 250,000 USD (about 195,000 €), with a 95% refund guaranteed by contract with a possible flight after the first 500 or so passengers;



-10% deposit (25,000 USD or about 19,000 €) with a possible flight about two years after the beginning of the commercial certification (i.e. possibly after 2017).

The extra cost for the experiment accommodation would be around 50,000 USD (about 38,000 €) for a payload of the size of the NASA Shuttle Mid-Deck Locker.

The *XCOR Aerospace* company offers the possibility to book a flight for a total amount of 95,000 USD (about 75,000 €), by paying a deposit of 20,000 dollars (about 15,500 €) for a flight in late 2014 on the *Lynx Mark I*, or the *Lynx Mark II* in 2015.

The cost proposed by *XCOR Aerospace* company for a first flight in late 2014 (at the end of the series of test flights) on the *Lynx Mark I* for a scientific-pedagogical mission would be 75,000 USD (about 59,000 €).

Table 2 summarizes the financial characteristics and dates for the flights proposed by these two companies.

TABLE 2: CHARACTERISTICS FINANCIAL AND DATES

	<i>SPACESHIP COMPANY (Virgin Galactic/Scaled Composite)</i>	<i>XCOR AEROSPACE</i>
Total cost	250,000 USD (approx. 195,000 €)	75,000(*)/95,000 USD (≈ 59,000(*)/75,000 €)
Deposit	(1) 250,000 USD (2) 25,000 USD	20,000 USD (approx. 15 500 EUR)
Estimated date of flight	(1) 2014 (2) After 2014	<i>Mark I</i> : end of 2014 <i>Mark II</i> : 2015 <i>Mark III</i> : 2016
Cost Supp. for experiments	About 50,000 USD for a Mid-Deck Locker sized payload	Included in the cost of the flight for the experiments embedded in the cabin and in the 2 rear canisters .

(*) for a 1st flight

3.3 Recommendations

In view of the proposed costs, possible dates of flights and possibilities of experiment accommodation, the possibility offered by *XCOR Aerospace* appears most interesting:

- the cost for a first flight (75,000 USD, approx. 59,000 €) is more than three times lower than that proposed by *Virgin Galactic* (250,000 USD, approx. 195 000 €);
- the date of end of 2014 is closest and likely to be more credible than that which could be proposed by *Virgin Galactic* (after 2017, after the flight of the first 500 or so first passengers);
- the possibilities of experiment accommodation are well-established for the *Lynx* spaceplane of *XCOR Aerospace*, unlike the *SpaceShipTwo* spacecraft which seems to be able to carry passengers only for the first few years;
- the cost for experiments accommodated in the cabin and in the two rear canisters of the *Lynx* would be included in the flight cost.

The shuttle *SOAR* studied by the *Swiss Space Systems S3* company cannot be considered at present as it would not be operational before 2017. Once it becomes operational, its use for scientific flights will definitely present many advantages.



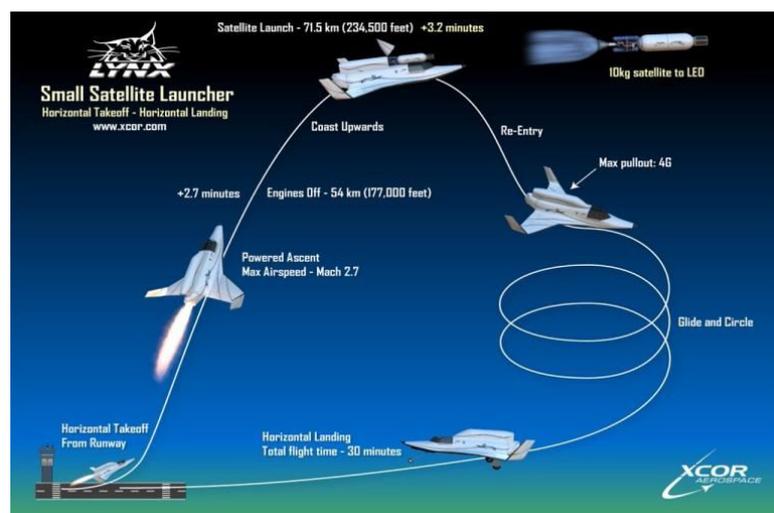
The Association recommends to organize a first series of missions with the *Lynx* spaceplane of *XCOR Aerospace* for scientific, technological and pedagogical experiments. This would allow to build a first hand experience to study further the possibilities offered by Virgin Galactic for a next series of missions and to consider the *SOAR* shuttle from the *S3* company for suborbital flights in the future.

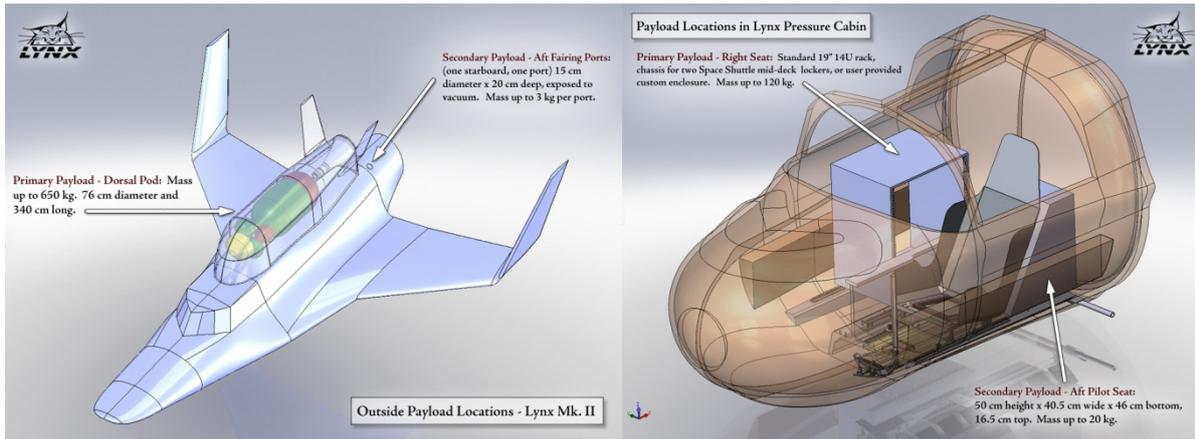
4. XCOR AEROSPACE AND THE LYNX SUBORBITAL FLIGHT

The American company *XCOR Aerospace* has developed several space subsystems (rocket engines, structures, airplanes, aircraft,...). Since several years, this company develops a concept of spaceplane, the *Lynx*, that can carry a pilot and a passenger astronaut for suborbital space flights (see <http://www.xcor.com/>; Video: <http://www.youtube.com/watch?v=3a-11tb1rPg>).

Technically, the *Lynx* spaceship is a small spaceplane, which takes off from a space airport in the California Mojave desert like a normal plane, carrying a pilot and a passenger astronaut sitting both at the front of the aircraft, and wearing pressurised flight suits. The spaceplane is powered by a liquid fuel rocket engine to its apogee before returning to land like an airplane. Three models are planned: *Mark I*, *Mark II* and *Mark III*. The first, *Mark I*, is planned to begin a series of test flights in 2014 to Mach 2 at an altitude of 60-65 km. Based on the results of *Mark I*, the second model, *Mark II*, would start its flights in 2015 in Mach 3 up to an altitude of 100 km. The third model, *Mark III*, would follow in 2016.

The configuration of the cabin allows embarking experimental equipment behind the pilot's seat in the cockpit of the spaceplane and activated by the passenger astronaut. Two canister compartments at the rear of the spaceplane can also accommodate small experiments. Depending on the experiment mass and performances of the *Lynx* spaceplane, a microgravity environment can be obtained for about one minute for the *Lynx Mark I* and for three to four minutes for the *Lynx Mark II* during the suborbital flight.





Credit : *XCOR Aerospace* (<http://www.xcor.com>)



Credit : *Orbital Outfitters*
(<http://www.orbitaloutfitters.com/SpaceSuits.html>)



5. COMPARISON OF MICROGRAVITY RESEARCH PLATFORMS

The platforms used presently for microgravity research are compared with suborbital flights (see Table 3), as function of the level and the duration of microgravity obtained, the available experimental volume, the type of interaction, the waiting time for scientists, the approximate overall cost of a mission and the cost by experiment, which are based on the following assumptions :

- one experiment per fall in free fall towers;
- 12 experiments per aircraft parabolic flight campaign;
- 5 experiments per sounding rocket flight (these costs do not include the costs of development of instrumentation).
- a development cost of a few million and launch of the order of 20 k€/ kg have been considered for the ISS;
- 3 experiments per flight for suborbital flights (if more experiences can be accommodated, the cost per experiment would obviously decrease).

TABLE 3: COMPARISON OF MICROGRAVITY PLATFORMS

Platform	μg (g)	Duration	Vol. (m ³)	Inter-action	Waiting time	Cost	Cost/expt
Free fall towers	$10^{-3} \dots -6$	< 5 s	< 1	TC	≈ months	> 10 k€	≈ 5 k€
Parabolic flights	$10^{-2} \dots -3$	≈ 20 s	> 10	Hum.	≈ months - 1 year	≈ 1.5 M€	≈ 125 k€
Sounding rockets	$10^{-4} \dots -5$	5 - 13 min.	< 1	TC	> 2 years	> 2 M€	> 400 k€
ISS	$10^{-2} \dots -5$	years	> 1	Hum.	> 5 years	> 10 M€	≈ 1-5 M€
Lynx I / II-III	$10^{-2} \dots -4$	1 / 3-4 min.	< 1	Hum.	≈ months	≈ 75 k€	≈ 25 k€

(TC = telecommands, Hum = operator or human subject)



We note from this Table 3 that:

- the only conventional platforms for experiments with human subjects or operators are aircraft parabolic flights and the ISS;
- aircraft parabolic flights are limited by the duration of microgravity (≈ 20 s) and the ISS is limited by the cost of experiments and waiting time.

These two factors greatly handicap the research to be carried out by or on human beings, particularly for scientists involved in microgravity research.



6. ADVANTAGES OF LYNX SUBORBITAL FLIGHTS

The advantages of using the *Lynx* for scientists are multiple and can be classified into three categories.

6.1 Main scientific advantage: intermediate duration between parabolic flights and ISS

Suborbital flights with the *XCOR Aerospace Lynx* are a new experimental platform, which, by providing a period of one to four minutes depending on the model of the *Lynx*, to bridge the time interval of microgravity between aircraft parabolic flights (20 s) and orbital flights on the ISS for experiments with human subjects and operators.

For medical and human physiology experiments, all scientists are unanimous: aircraft parabolic flights allow observing the beginning of certain changes in physiological systems but they do not allow studying the adaptation to microgravity on a longer time scale. For this, suborbital flights of one to four minutes are better suited for this kind of research.

Furthermore, the adaptation on a time scale of one to several minutes is not accessible for research on astronauts launched to the ISS.

The same goes for some physical science experiments where one would like to verify an experimental configuration for longer than 20s before sending it to the ISS in order to maximize the chances of success and optimize budget investment of a mission on the ISS.

It should be stressed that this new experimental means of suborbital flights is complementary to other microgravity platforms and cannot be substituted for these other means.

6.2 Logistical advantages for scientists

1) Ease of access

Approaches and technical reviews are minimized and are equivalent to what scientists are already doing for aircraft parabolic flights.

2) High frequency

The spaceplane *Lynx* will fly regularly. *XCOR Aerospace* plans to make up to 3 to 4 flights per day, allowing to repeat quickly several times experiments, ensuring a high scientific return.

3) Multidisciplinary platform

The *Lynx* suborbital flights offer the possibility to embark several experiments in biomedical fields and physical sciences and to conduct other types of experiments in the upper atmosphere.

6.3 Programmatic advantages

1) Low-cost

The total cost for a flight is of 95,000 USD (about 75,000 Euros), which is much more interesting than other platforms when costs per experiment are compared (see Table 3). If we consider accommodating three experiments only, each experiment would cost approximately 25 k€, i.e. 5 times less than an experiment in parabolic flights, for a duration of one minute instead of 20 s.

Even for human physiology experiments, for which typically 3 to 6 subjects are tested per parabolic flight campaign, the costs of suborbital platforms like the *Lynx* are less than or equivalent to those of parabolic flight campaigns, but with the advantage of offering a much longer microgravity exposure.



2) Diversification of flight opportunities

The organization of a series of suborbital space missions for leading edge scientific experiments from researchers already selected by space agencies and waiting for a flight opportunity will provide independently more frequent flight opportunities to researchers.

3) European expertise

It is important to be among the first users of experimental suborbital flights before these become routine, to allow scientists and engineers to be among pioneers of using these new space opportunities. Using early *Lynx* suborbital flights will thus develop a European expertise as an economic asset for these suborbital flights since these will develop in the future.

7. SCIENTIFIC AND TECHNICAL EXPERIMENTS

Scientific experiments on board the *Lynx* will be able to use either the environment of weightlessness with, depending on the *Lynx* model, an approximate duration of one to four minutes, or the outer space environment at an altitude of 60 to 65 km or up to 100 km, hardly attainable by balloons or stratospheric aircraft or space orbital platforms.

The scientific and technical fields in which these experiments can be conducted are multiples: from human physiology to materials science, from Earth observation to measurements of parameters of the upper atmosphere, from technological tests in microgravity to the qualification of on-board space environment. Many scientists have already marked their interest to take part in these flights.

Examples of scientific experiments that can be conducted in real time on board the *XCOR Aerospace Lynx* are listed non-exhaustively here below:

Physiology

- Heart rhythm and its variations by electrocardiography
- Brain electrical activity by electroencephalography
- Cognitive experiments in microgravity

Biology

- Study of biological systems in microgravity and exposure to the space environment and atmospheric reentry
- Chemistry of cellular membranes in microgravity

Physics of fluids

- Formation of multilayer system fluid in microgravity
- Measurement of diffusion coefficients in fluid mixtures
- Behaviour of fluids near their critical point
- Studies of cryogenic fluids

Atmospheric physics

- Measurement in-situ of atmospheric parameters by radio sounding
- Measurement on atmospheric Ozone and other gases

etc.

In addition, pre- and post-flight experiments can be conducted on the passenger astronauts that will participate in these suborbital flights to measure the degree of adaptation to weightlessness and potential change in physiological systems.

Other experiments can be considered and researchers are invited to contact the Association.



8. STUDENT EXPERIMENTS

To prepare today's students, tomorrow's researchers, for research in weightlessness and space technologies, it is also proposed to embark on each flight an experiment proposed by students that will be conducted by the passenger astronaut during the flight.

This student experiment will be selected by a scientific board and supported by a group of engineering students.

9. CONCLUSIONS

It is concluded that the interest and scientific benefits of a flight of one to four minutes in weightlessness for experiments in physics of fluids, human physiology and biology in microgravity justify to organize this type of mission.

It is emphasized that suborbital flights are complementary to the other classic experimental platforms and cannot replace them. Suborbital flights will be added to the panoply of experimental means offered to researchers. The use of parabolic flights and the ISS will continue but, unfortunately, with cost and growing delays for researchers. New opportunities for flights must therefore be given to researchers

This new low cost approach, economically and scientifically justified will allow continuing the fundamental and applied research despite the economic crisis since research is a factor of economic recovery. In particular, space research in microgravity is a factor of economic growth with many practical applications in everyday life.

The Suborbital Research Association therefore recommends to organize a first series of scientific flights with the *XCOR Aerospace Lynx*. Interested researchers are invited to contact the Association.



(See : <http://www.youtube.com/watch?v=3a-11tb1rPg>)

