DESIGN ASPECTS OF INTIMATE SPACES – A CASE STUDY IN THE CABIN INTERIOR DESIGN FOR THE XP SPACEPLANE

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Rocketplane Global (RpG) is one of the leading new suborbital spaceplane development and operations companies, based in Oklahoma City, OK. The XP spaceplane is a horizontal takeoff and landing vehicle which uses conventional afterburning turbojets for takeoff and landing operations and a LOX / kerosene rocket engine for the ascent to space. The XP cabin and life support system is designed with multiple redundant systems to enable a "shirtsleeve environment" for the passengers. With no need for a bulky emergency pressure suit and helmet, the passengers will have a much more intimate connection with the cabin interior environment. Accordingly, great attention to detail is being given to all elements of the interior design, including the seats, monitors, instrument panel, controls as well as the interior hull surfaces and textures and trim. The goal is to provide a truly unique design environment that enhances the spaceflight experience and provides a unique look and feel to the XP cabin as part of the RpG brand building and product differentiation strategy. The design process as well as the complete cabin design and interior finishing details will be presented in this paper. RpG has teamed with Frank Nuovo, a world-renowned industrial designer with experience at BMW / DesignWorks, Nokia, and most recently the Creative Director for Vertu, Nokia's line of ultra-premium cellphones.

I. INTRODUCTION

The XP spaceplane is a six seat vehicle with one pilot and five passengers. The 2 – 2 – 2 seating configuration is contained within a pressurized cabin volume of about 30 cubic meters (roughly equivalent to a large sport utility vehicle). A unique feature of the XP seating configuration is that the front right "shotgun" seat is a passenger seat, affording a wonderful and unmatched view of the Earth from the large front windows. In fact, the view from the second and third rows still provide significant front window views in addition to multiple side windows for each passenger. In addition to all the windows, each passenger will have their own personal video screen with individual control functions to pull up images from any of the eight on-board video channels, as well as call up and display flight data or even scroll through uploaded pictures of their loved ones if they desire. The basic engineering layout of the XP is shown in Figure 1 below.

The majority of the fuselage is of course occupied by the propellant tanks needed to carry the fuel and LOX needed to accelerate to Mach 3.5 for the zoom climb to the 100 km apogee. The aluminum structural frames are about 2" thick, so the total wall thickness of the fuselage is about the same as in a typical business jet.

A detailed view of the cabin portion of the XP is shown in Figure 2 below. The nearest spatial analog is really the look and feel of a large American sport utility vehicle or minivan with captain's chair seating. The fuselage diameter of slightly less than six feet is comfortable but not wide enough for the sort of zero G gymnastics that some of the suborbital competitors discuss. However, RpG flight crews and engineering staff believe that in the short amount of weightless time available during a 100 km suborbital flight (about 3 – 4 minutes) that it is not a safe flight practice to release from the seatbelts in any case. The risk of injury or interference with the pilot if the customer is not properly back in their seat by the time of reentry is too great to take chances with. Moreover, weightless gymnastic play is best done and most enjoyable in a large volume space during a parabolic aircraft flight.

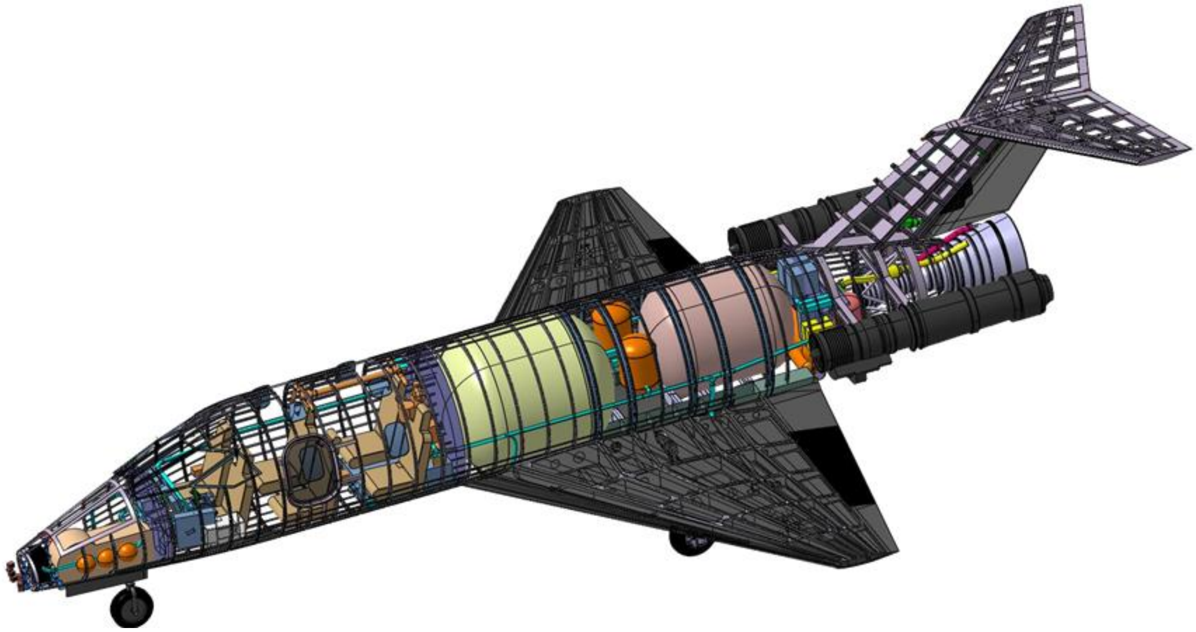

Figure 1. XP Engineering Systems Layout

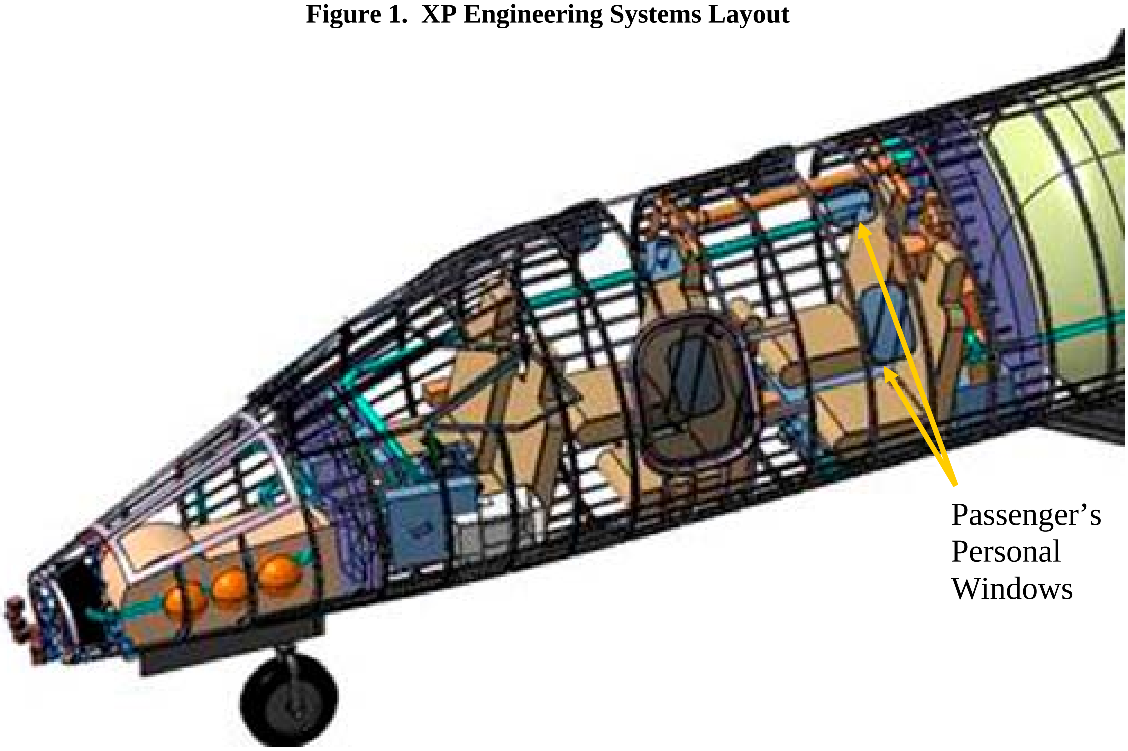

Figure 2. XP Cabin Layout Details and Window Locations

Two plug-type hatches are located on either side of the fuselage between the first and second row of seats. These hatches are considerably smaller than the door of a typical business jet and are sized to be the minimum opening that can still pass the seats, interior equipment and especially a double mid-deck locker sized payload for microgravity flights. The hatch clamps are released and the hatches are removed completely for entrance and egress. Part of the safety training for crew and customers is the familiarization with the hatch release procedures in a hands-on environment of a cabin training simulator.

The environmental control and life support equipment is located between and behind the last row of seats just forward of the aft pressure bulkhead. Once the hatches are sealed the cabin interior is a closed system for the entire one hour duration of the flight. Vacuum dewars of liquid oxygen and liquid nitrogen provide fresh cabin air with sufficient volume to provide make-up pressurization gas in the event of a 1” diameter hole or equivalent window seal rupture. Windows are triple glazed, each with their own seal capable of holding full cabin pressure at altitude, so this level of redundancy in the primary leak path provides enough safety that the emergency makeup air function of the life support system can be the primary system and pressure suits are not needed. The phase change energy from liquid to gaseous form provides the cooling for the cabin during the flight. Carbon dioxide scrubbers and water vapor are removed with each air change cycle. A duct located above each passenger’s head provides a constant flow of air across the face to remove spent breath and return it to the ECLSS system. An additional emergency oxygen system quick-don breathing mask is included for each passenger as an added level of redundancy. All life support systems and failure modes will be tested in a specially designed test chamber at the Paragon Space Development Corp facilities in Phoenix to assure safety and reliability prior to high altitude flight testing.

Due the multiple levels of redundancy in the life support system, window seals and door seals, the XP passengers will be free to wear clothing of their own choosing during the flight. Customers may choose to wear a standard astronaut-type Nomex flight suit, a custom designed flight suit, or any other type of wear provided it does not restrict movement during an emergency egress. Since there is no safety requirement to wear a pressure suit due to the redundant life support systems discussed above, the Rocketplane design team believes that this provides a significant enhancement to the overall flight experience. Pressure suits are bulky and uncomfortable and helmets obstruct vision. Moreover, there is a significant recurring maintenance expense as well as a big up-front investment in an inventory of suits that will fit all customer sizes.

II. PREVIOUS DESIGN EFFORTS

Until recently, the cabin interior was just a starkly rendered engineering layout with notional seats and a minimum of attention paid to functional layout matters, primarily in the pilot’s instrument panel and control interface layout. CGI artists doing XP renderings and videos would either copy a Recaro sports car seat or develop a simple and uninspired functional seat rendering based on the engineering drawings. Early interior renderings of the XP are shown in Figures 3 and 4. At the time a Learjet fuselage was being used as the hull of the XP so the window placement and size was predetermined by the locations found in the existing aircraft.

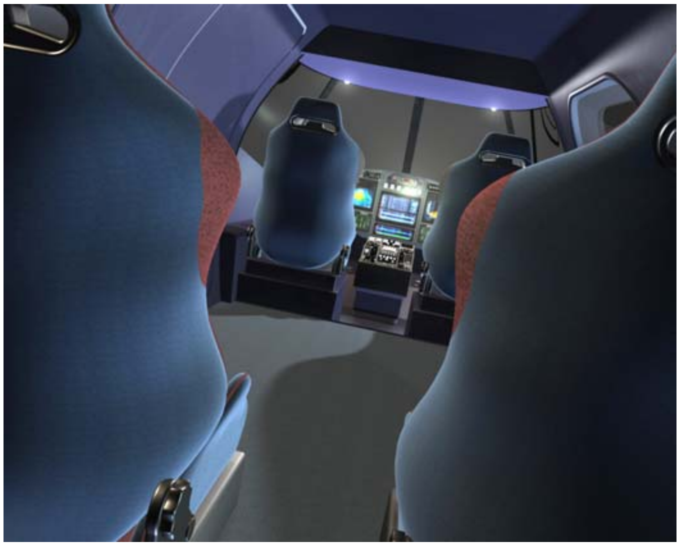

Figure 3. Early 2004 XP Cabin Interior

Figure 4. Another early cabin interior

III. THE COMPETITION

In September 2006 Virgin Galactic introduced its cabin design concept with a video and a full scale cabin mockup at an event in New York. Virgin had hired noted designer Philippe Stark to come up with a cabin and seating design, along with some fanciful flight suits and helmets. All were shown in an elaborate CGI animation of a SpaceShipTwo flight from the New Mexico Spaceport. The Virgin cabin design and flight suit was vaguely a derivative "Star Trek" theme visually, and the animation showed what appeared to be a huge cabin with lots of room for zero G gymnastics. The announced cabin diameter of 2.3 meters[1] is larger than the XP's 1.7 meter diameter. The Virgin cabin is shown in Figure 5 below.

Figure 5. Virgin Galactic cabin mockup [1]

In June 2007 EADS Astrium unveiled the design for their suborbital spaceplane at the Paris Air Show. Their vehicle architecture was almost identical to the XP, and in fact the Chief Engineer for the EADS program acknowledged that they had copied the XP design in an interview[2]. However, EADS had hired the noted designer Mark Newson to do their cabin interior. A rendering of the EADS spaceplane cabin is shown in Figure 6 below. With our primary competition both showcasing world-class designers and innovative interior treatments, we had no option except to respond in kind or risk losing market share to the competition due to the "style" factor of the different spaceplane interiors. Rocketplane recruited Frank Nuovo to develop the XP cabin design concepts shortly after the Paris Air Show in 2007. The development of a unique "look and feel" for the XP began in late 2007 and continues as part of the overall vehicle development program, while monitoring the designs and cabin features of the suborbital competition. Moreover, Rocketplane management believes that with multiple competitors to choose from the customers will be making buying decisions on an integrated impression involving ergonomics, touch factors, ease and variety of viewing options, and cabin personal equipment in addition to world-class styling elements that all part of any high end consumer discretionary spending choice. Frank Nuovo designed a successful line of luxury mobile phones for Vertu costing thousands of dollars in a marketplace where most phones are essentially free. This design driven brand differentiation also applies to the entire XP cabin interior in a competitive marketplace.

Figure 6. The EADS "TBN" spaceplane cabin[3]

IV. THE PILOT'S FLIGHT STATION

The pilot sits in the front left seat with an F-16 style flight control interface consisting of a control stick in the right hand and a throttle body in the left hand. Two Barco multifunction LCD displays provide all necessary flight data and vehicle health and performance data to the pilot. Additional avionics in the instrument panel include radios, transponders, circuit breaker panels, video and audio intercom controls, and backup instruments and gauges. Conventional rudder pedals provide steering and braking functions during ground taxi and yaw control during flight.

Since the XP flies in both conventional atmospheric flight mode and in exoatmospheric weightlessness mode during the course of the 45 minute flight, the pilot and the flight computer must be able to provide constant three axis control during all portions of the flight. The same control inputs from the pilot to the stick, throttle and rudder pedals work identically in both modes, with the flight computer switching between aerodynamic control surface actuation and reaction control thruster firings depending on where the XP is during the flight profile. The flight station layout is shown in Figure 7 below. Single pilot control with necessary safety and reliability is proven in new generation small business jets and the Rocketplane engineering team believes that the same design principles will work in aerospace planes. Moreover, several competitors including EADS Astrium, XCOR and Project Enterprise plan single pilot operations and Armadillo and Blue Origin plan on using remote or autonomous flight operations[4].

Figure 7. XP Pilot's Flight Station

The front right seat or "shotgun" seat is actually a premium passenger seat or alternatively a Payload Specialist workstation seat during a microgravity research flight, satellite launch mission or remote sensing flight as described in other papers at this conference. The LCD multifunction display for this seat can be programmed for a variety of missions and control functions. In effect this seat has a fully functional computer workstation that can be linked to both on-board payloads and directly to Mission Control. A mouse control touchpad is located in the armrest of the front right seat for computer input during the g loaded portions of the flight profile in addition to touch screen inputs on the computer screen. The payload data bus will use standard Ethernet protocols and USB plug interfaces, so any payloads or equipment installed in the XP can be easily integrated and tested prior to flight.

V. GOING BEYOND ENGINEERING

The majority of the revenue from XP flight operations is expected to be derived from commercial space tourist flights. At a price of $200,000 or more this is by definition a high-end luxury consumer discretionary spending decision. For most customers it will be a once-in-a-lifetime event. The decision about which spaceflight operator to fly with will be based in part of the perceived safety and comfort of each vehicle design, in part on the location the space vehicle is flying from, and in part on the intangibles such as interior design of the spacecraft and the "coolness factor" associated with the overall perceptions of each vehicle and operating company. A 2006 market survey by Incredible Adventures[5] showed that the preferred vehicle architecture was the one-piece horizontal takeoff and landing spaceplane like the XP, so we already know we are hitting that sweet spot.

The last remaining element in the design process is completing the cabin interior, seating and passenger equipment interfaces so that the overall impression is analogous to the finest high performance luxury sports car, but with additional features unique to the space flight experience. In order to accomplish this goal, Rocketplane teamed with Frank Nuovo, a renowned industrial designer. Designing to the demanding standards of a luxury car owner or the purchaser of a mobile phone costing $5,000 or more was exactly the type of high-end designer experience needed to execute the cabin design process for the XP. Designs will be tested in Virtual Reality labs with RpG customer focus groups, and again in a full scale functional cabin mockup prior to finalizing the cabin designs.

VI. CABIN SEATING

The first element identified in the design analysis process was the seating. The principle is that everything in the design flows outward from the direct tactile interface between the passenger and the vehicle. It was quickly agreed that the typical business jet seat expression of cushy thick leather padding and burl wood accents was the wrong direction for desired interior vocabulary and expression.

Instead a synthesis of a historical spacecraft seating design and a contemporary office seating design was chosen for further development. Weight is always a critical factor in spacecraft design, and this was never more the case than with the Apollo capsule design where every once of weight going to the Moon and back required tremendous quantities of energy to propel it there. The seats in the Apollo capsules were a simple aluminum frame covered with a mesh to support the weight of the astronauts. The Apollo seats are shown in Figure 8 below.

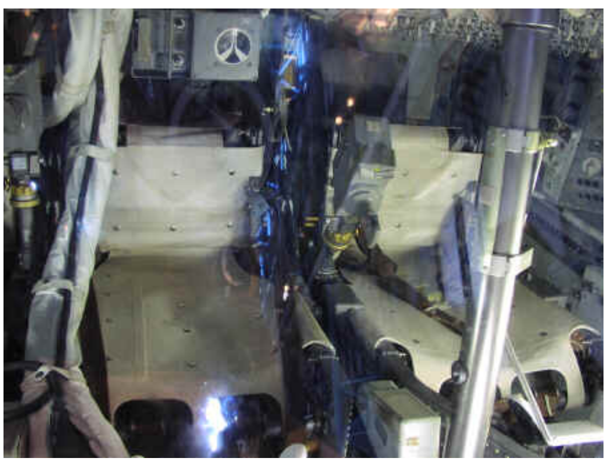

Figure 8. Apollo Command Module seating.

The contemporary design analog is the award-winning Aeron office chair by Herman Miller[6]. This chair uses a tubular frame and mesh back and seat that provides support and ventilation while stretching to provide individualized comfort. Since the passengers in and XP flight experience loads of over 3 G's on ascent and 4 G's on reentry for up to a minute, comfort and support for the entire body are critical elements in the seating design.

The original design studies for the seating are shown in Figure 9 below. A small personal video monitor is built into the structural spine along the center of the seat back.

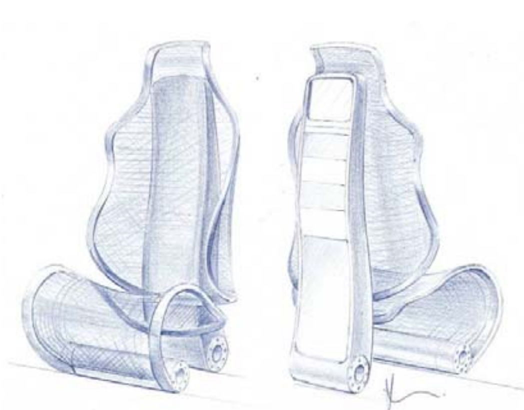

Figure 9. Initial XP seating design sketches.

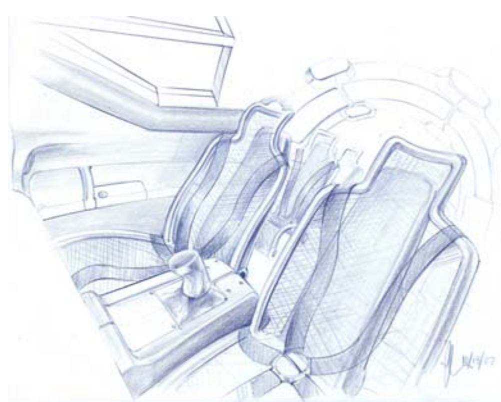

Figure 10. First XP cabin design treatment sketch

The integration of this mesh-type seating element into the first iteration at the overall cabin interior treatment is shown in Figure 10 above. The light airy feel of the mesh seats provides a much more open feeling to the entire cabin, while at the same time saving both weight and cabin volume that would otherwise be allocated to seat cushion thickness. At this point everything is still at the "soft pencil" hand drawing stage of design, but the look and feel of the cabin expression is already becoming apparent. Rocketplane management and the engineering team enthusiastically embraced this design direction, and included these design sketches in the rollout event for the new XP overall vehicle design at the X Prize Cup in October 2007[7].

The next step in the design process was to move from hand drawing sketches to CAD design so that a virtual XP interior could be created for study and feedback from focus group customers. An early iteration of the CAD interior rendering is shown in Figure 11 below.

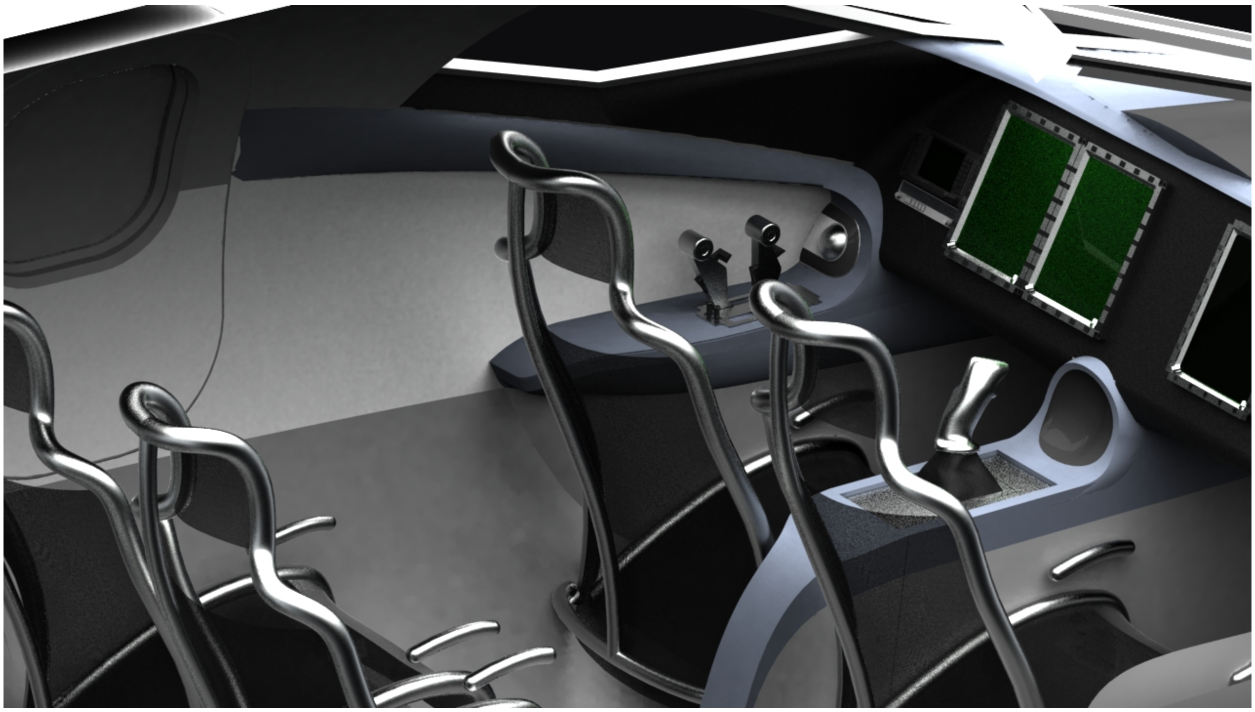

Figure 11. First XP cabin interior CAD rendering.

A cool tone color palette of blues and grays was also selected at this time. The selection was based on the fact that the Earth as seen from space during daylight is incredibly bright and vivid, and it is specifically this view that the customers are paying big money to see. An understated yet sophisticated interior color scheme they compliments the bright colors of the Earth was considered to be the most appropriate color choice. The primary driver for a space tourism flight is after all the view outside from the 100 km altitude, so the cabin interior should compliment and enhance this experience rather than competing with it.

VII. SPACE VISION

Further design development included integration of the personal video displays into each seat back. This equipment is an integral part of the XP flight experience, with each passenger having individual control of the imagery in front of them to augment their direct views out of the side and topside windows for each seat and the panoramic view out the forward windscreen. A second round design iteration CAD rendering is shown in Figure 12 below. More finishing details are now coming out in this design cycle.

Another unique design feature incorporated into the cabin interior during this design cycle was the addition of electroluminescent panels into the soft finish elements of the cabin. These panels will change color during different phases of the flight profile to give passengers an intuitive visual cue to the beginning and end of each phase of the flight, especially the onset of G loads at the start of the rocket powered ascent, the beginning and end of the weightless period, and the reentry G loading. In effect the entire XP cabin interior will be communicating to the passengers in a natural and intuitive way to augment the flight experience.

Figure12. Second round design iteration.

An additional design element of the cabin interior is the selection of natural and renewable / recyclable materials for the interior finishes. All plastic surfaces and structural substrates to the leather covered areas will be made from bio-plastic developed from resins derived from cornstarch as the raw feedstock. All aluminum trim will be made from recycled cuttings from the XP structural fabrication process. This design philosophy expression mirrors the operational characteristics of the XP, where the liquid oxygen is manufactured on site from renewable wind, solar or wave energy and the RP and jet fuel for the engines is manufactured from an algae-based biofuel process. The XP will be certifiably "green" and the flight operations will be 100% carbon neutral. Outgassing tests on cabin interior materials will also be performed in the Paragon test chamber while running in full closed loop life support mode to determine safe trace element levels. Flame resistance properties will be tested in accordance with FAA standards for small aircraft, and a fire monitoring and suppression system will also be included in the cabin. It should be noted that in the US commercial suborbital spaceflight is licensed rather than permitted and is inherently different from flying in a FAA type-certified aircraft. Each space vehicle is unique and all safety and reliability matters are reviewed individually by FAA / AST Office of Commercial Space Transportation. Standards and practices from commercial aircraft MAY be incorporated into vehicle design and operating practice, but there are no absolute requirements or standards anywhere in the commercial human spaceflight operating environment.

The core of the suborbital flight experience is of course the view of the Earth from space and seeing the sky turn black and the stars come out in daylight with the luminous blue band of the atmosphere showing below. The XP cabin configuration provides views out of the front windows from every seat, and this is a truly unique advantage of the design. Even in the Space Shuttle, most of the astronauts do not get to see out the front windows during the launch. The view from the back row passenger seating is shown in Figure 13 below. With front, side and top windows plus individual video screens with multiple camera views available each passenger will be able to be fully immersed in the viewing experience and share the experience with the others on board and with their friends and family on the ground at the Mission Control center via high bandwidth audio and video links.

Figure 13. XP cabin forward view from rear seat position.

VIII. CONCLUSION

Each design iteration of the XP cabin interior has honed the focus on the fine grain details and individual elements and touch points experienced by the customers during the spaceflight. Until now all work has been done in the virtual environment, but in ergonomics and styling a "hardware in the loop" physical testing program is necessary prior to finalizing the cabin interior design. The next step in the process is to test the lessons learned from our own design reviews and the design evolution in our competitors with high fidelity cabin mockups and virtual reality window projections to assure that comfort, functionality, safety and enjoyment of the spaceflight experience are optimized. The seat, window size and placement, passenger control systems and safety equipment will all be extensively tested by customer focus groups before the cabin design process is considered complete.

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