Spaceflight vs. Human Spaceflight

Spaceflight vs. Human Spaceflight

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Spaceflight vs. Human Spaceflight

Why is it different?

- Many countries have a spaceflight program. What makes a human spaceflight program so different?
  - *There's a perception that human spaceflight doesn't have to be as complicated as it's been.*
  - *There's another perception that the safety regulations and redundancy requirements are unnecessarily strict for human spaceflight.*
- There are far more countries/organizations that have successful unmanned spaceflight programs than those with successful human spaceflight programs. Why?
  - ***Because human spaceflight is complex, demanding on launch vehicles and very difficult.***
  - ***The consequences of failure are much greater than with unmanned flight.***

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Why is it different?

- Unmanned flight
  - *A space vehicle is generally a "passive" payload on the launch vehicle (not actively involved with launch).*
    - Launch vehicle responsibility is to deliver payload to the right orbit unharmed
    - Payload program is responsible for mission from that point onward.
  - *Most missions do not have a return element.*
  - *Space vehicles are intended for exposure to space and generally only have systems to protect against thermal extremes, radiation, meteoroids/orbital debris, vacuum and other space extreme conditions rather than providing a protected environment against those conditions.*

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Why is it different?

- Manned flight
  - *A manned space vehicle is active and must be ready to abort even during launch. Crews need some measure of control, even during launch to address unanticipated failures.*
    - Ensuring the crew's survival takes precedence over other mission imperatives.
  - *Manned vehicles must provide for safe return, reentry and landing of the crew*
    - Propulsive, control, thermal protection and systems drive shape, mass, and volume requirements and may impose trajectory limitations.
  - *Crews cannot be exposed to space and considerable technology, mass, and volume must be expended to preserve their environment and provide consumables.*

The primary imperative to protect the crew and return them safely drives a particular mindset described in the following charts.

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Always have an escape route

- *A failure path should always have at least one option where the crew can survive. More options are better. This has driven many provisions in past programs.*

  - *Fault tolerance is only part of this. It can also mean work-arounds, alternate paths and even manual operations to safe the crew.*
  - *This philosophy drives the need for emergency systems like those for abort/escape, fire protection, safe haven and even rescue.*
  - *This philosophy requires a cognizant and enabled crew (so they can take charge if necessary)*
  - *This philosophy requires a knowledgeable and responsive ground support team to provide immediate alternatives in case of emergency.*

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Protect For, Yet Use the Human Element

- *People, though capable of error, provide an invaluable resource.*
  - *People can and do make mistakes and it's hard to predict how they might make them.*
    - Two action implementation of critical functions and in depth training can both reduce error.
  - *People are capable of being part of the solution, particularly for situations <u>no one ever anticipated</u>.*
    - Autonomous systems cannot address unanticipated conditions
    - **The value of this human capability cannot be overstated.**
  - *In order to allow the crew to address unanticipated situations, they must have:*
    - Accurate information about the design
    - Accurate information about what is happening at that moment
    - Control of the critical systems to invoke changes

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Learn From Your Failures

- *The policy to learn from past mistakes is written in blood.*
  - *Catastrophic failures tell us what went wrong, what we failed to do, and what we failed to anticipate.*
  - *Failures that were not catastrophic but could have been can be just as important.*
    - Too frequently, near misses are remembered as “successes” and dismissed
    - Understanding how these near-tragedies were survived allows us to understand how previous design/systems/training succeeded so we can emulate that.
  - *Recurring failures, even if survived, should be red flags.*
    - Surviving a failure does not mean “prove” it’s safe.

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Test Like You Fly - and Test It Well

- *No test program is as expensive as a flight failure particularly a catastrophic one.*
  - *Even previously proven hardware should be tested in new applications.*
    - Space, launch, and reentry environments are extreme and can have profound impacts on component function and material properties.
  - *Integrated and end-to-end testing are extremely important, even though challenging to perform.*
    - Hardware and software that worked effectively individually may not do so when working together.
    - Test equipment and testing that does not exercise flight circuits may mask some failure conditions.
  - *Hardware should not fly until free of known defect and tested beyond its expected conditions.*

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The Big Picture

- It's tempting for nascent programs to focus on launch vehicles at first.
  - *Launch is a high risk phase and it's difficult to launch heavy payloads.*
    - Launch may also be what a program already has expertise in.
- However, focusing primarily on launch while other aspects of the space systems are undeveloped is risky since they also can drive launch vehicle requirements or take a long time to develop. Other aspects include:
  - *Mission profile*
  - *Space vehicle design and return/reentry/landing scheme*
  - *Abort/escape/emergency systems*
  - *Environmental and control systems*
  - *Operations/training/testing support*

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What do you want to do?

- The parameters of the chosen mission drive the provisions required for ground support and communication, space vehicle(s) as well as launch vehicle requirements.
  - *What is your destination? International Space Station (ISS)? To be a space station? Suborbital hop for tourism? Go to the moon or mars?*
    - Where you go drives interfaces, shielding, propulsion, certain reentry parameters and can drastically change how much power and lift capability is needed from the launch vehicle.
  - *How long will you be up there?*
    - Duration drives workspace needs, shielding (perhaps for thermal protection system, too), spares, consumables vs. regeneration considerations, human impacts: medical, physical, mental.
  - *It's tempting to want one vehicle that can perform more than one mission profile/type.*
    - Doing so requires compromises that may leave some missions burdened with unnecessary elements and others under-designed.

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How will you get the crew up there?

- Launch may not be the only concern, but it is still a major concern. Launch is a significant risk contributor and a reliable system is imperative.
  - *If the launch vehicle is new or derived (new but using some elements of heritage hardware), testing programs are required to demonstrate integrated systems and reliability.*
    - Note that the use of heritage hardware in a new launch vehicle does not assure similar reliability.
  - *New designs might have the space vehicle contributing and/or controlling launch, as the Space Transportation System did.*
    - This all but precludes using an established design.
  - *However, even using a “standard” configuration with the space vehicle atop a multistage rocket as a payload, the human element can complicate controls and the destruct systems.*
    - See figure next chart.

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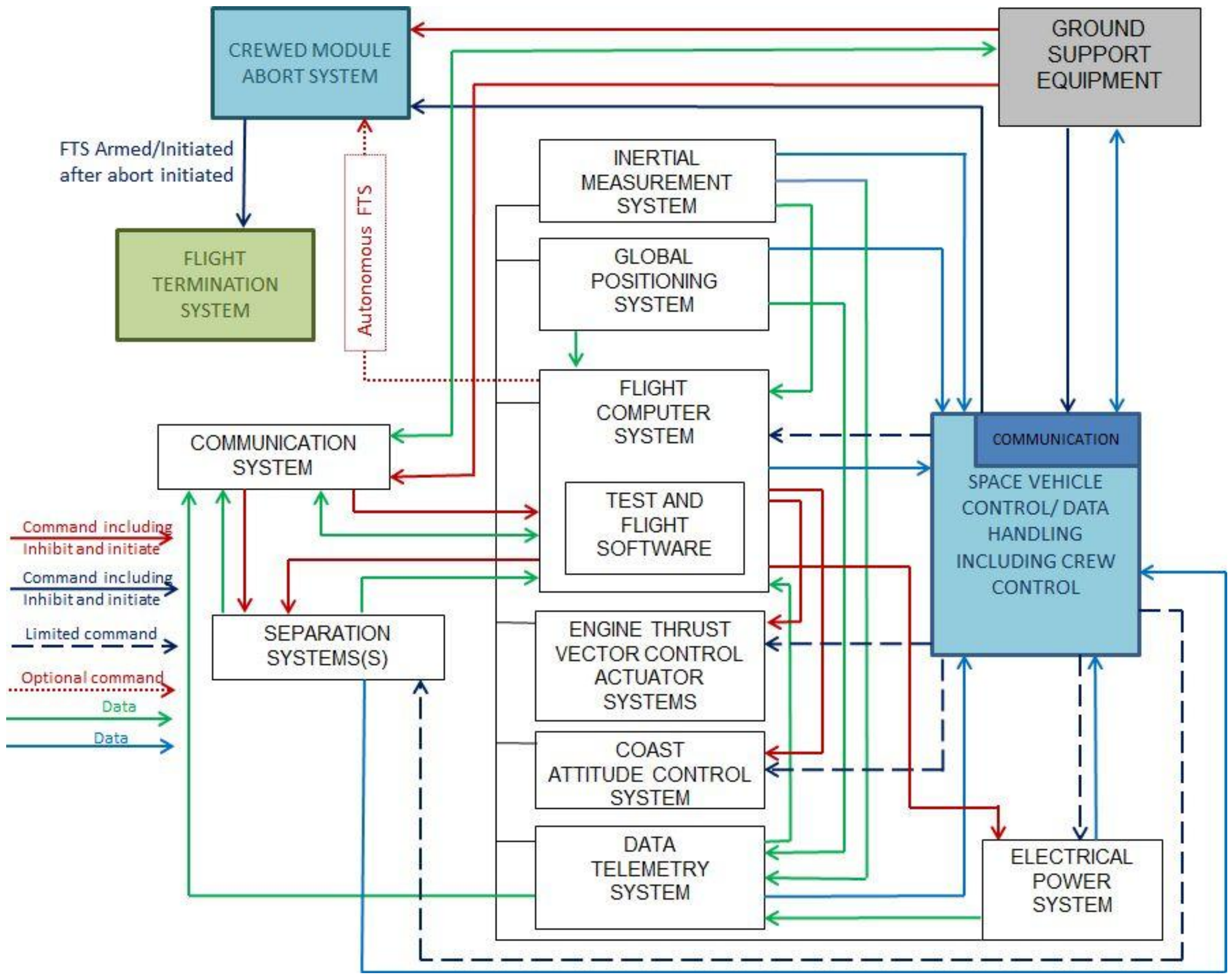
How will you get the crew up there?



Generic Launch Vehicle Functional Diagram with Man-Rating per NPR 8705.2. Man-Rating aspects in blue.

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How will you get the crew home?

- Reentry considerations and decisions drive space vehicle(s) design, control systems, thermal protection requirements, ground facilities/support, communication, and propulsion.
  - *Will the spacecraft deorbit itself or have disposable deorbit propulsion module (separate from the return module)? What shape will the reentry module be?*
    - Drives methods used for slowing down the vehicle (retro rockets, parachutes, shock absorbers, airbags or combinations of more than one) and thermal shields which add to mass and volume.
  - *How will you land?*
    - Runway landings are nice, but drive vehicle shapes that can be challenging to control and design.
    - Water acts as a shock absorber, but rescue teams need to be immediately on hand and good communication is essential.
    - Land landings require reliable slowing methods and require unpopulated areas for safety.

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How will you address crew environment?

- Closed tightly coupled systems can be tricky, and issues are often compounded by the tight weight/volume requirements.
  - *Oxygen and pressure systems are obvious but humidity and thermal protection need to be controlled, too.*
  - *Human waste (CO_2, biological waste) and trash/debris need to be addressed.*
  - *Off-gassing for toxicity and flammability must be addressed through material selection.*
  - *Workstation provisions for working in low gravity and preventing injury need to be assessed. Lighting and human factors need consideration.*
  - *Long duration flights need to consider radiation shielding, consumables, biological contamination, and room for exercise to prevent bone and muscle atrophy.*
- Although these systems don't need to be mature early, sufficient volume, mass and power to accommodate them must be available.

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How will you control the space systems?

- Manual control adds complexity but also versatility and can take the place of automation.
  - *Given the impact on designs, understanding what the crew can and can't control (at what stages) is important early. Software development can be a long lead item.*
    - Making controls so complicated that they can't be handled manually severely limits options in case of problems.
    - Manual control in lieu of autonomy adds human error and can eat up the precious commodity of crew time.
  - *In flight maintenance can be a huge boon (particularly on long missions).*
    - But maintenance requires tools and spares, which take weight on volume.
    - **The ability to perform in flight maintenance should not preclude good engineering practice in designing equipment.**
  - *Ground control can provide some support and backup for autonomous functions, but requires good communication coverage and dedicated knowledgeable personnel.*

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How will you address crew survival in an emergency?

- Emergency systems include abort/escape but also emergency repress and fire suppression systems.
  - *Sometimes, these are pushed off to be designed later.*
    - Many emergency system options are unfeasible or prohibitively expensive when retrofitting an existing design.
    - Sometimes the retrofitting options are so challenging that less than optimum solutions like crew rescue or long times in pressurized suits are used.
  - *Ideally, emergency systems are part of the design from the beginning*
    - They tend to eat up volume and mass.
  - *There is a school of thought that emergency systems should not need to be as reliable as systems in constant use since they will only be used after multiple failures.*
    - This author is not of that school of thought. A system that must work because it is an emergency must be more reliable, not less.
    - The lack of daily use makes maintenance and health checks more important for such systems.

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What are the provisions for testing, training and operations?

- Effective ground control requires access to and knowledge of designs and system functionality.
- Crew and operator involvement early in the design process can help make an effective design, one that works well in actual use.
- Effective use of the human element can be made/broken with training and operation.
  - *Training facilities should allow all key operational aspects of the various systems to be actuated in a flight-like manner.*
  - *Testing facilities need to be able to exercise components, subsystems and systems in a flight-like manner through all potential environments.*
  - *For what can't be simulated on the ground, modeling labs that take advantage of ground and flight test data will be required.*
- Operations personnel also need dedicated support facilities for flight support that allow access to data, but provide effective security to prevent unauthorized access to information and control.

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Is your management structure conducive to safety?

- Effective management empowers all other organizations and ensures they work together correctly.
  - *Management issues are cited in most accident investigations.*
    - Competing priorities can lead to oversights, short changing critical systems, mistakes and confusion. This is compounded if programs feel competitive with one another or possessive of “their” systems.
  - *Ideally, one organization has final say and responsibility for program and systems.*
    - Requires good communication from the lowest levels.
    - Requires no backlash for bringing bad news.
    - Requires a cultural shift; such a mindset can’t be mandated.
  - *However, even the best management system is also challenged by juggling many priorities with safety being but one of them.*
- A dedicated, empowered, and independent safety organization can be critical for any human spaceflight program.

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Conclusion

- The imperatives peculiar to human spaceflight may not be intuitive to designers, even designers highly experienced in unmanned spaceflight.

- A good understanding of the needs peculiar to human spaceflight and designing a system with all of those needs in mind can be key to a successful human spaceflight system.

Thank you