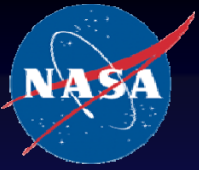


Helios High Altitude Long Endurance Mission Mishap





Solar Aircraft History

Pathfinder 1981, 98 ft Wing Span, T.O. Weight 560 lbs, 39 flights



Flew to record 71,500 ft in 1997

Pathfinder Plus 1998, 121 ft Wing Span, T.O. Weight 716 lbs, 7 flights



Flew to record 86,201 ft in 1998
205 flight hrs, 39 hrs above 50K

Centurion 1996, 206 ft Wing Span, T.O. Weight 1385-1801 lbs, 3 flights, 3.4 hrs



1999, 247 ft Wing Span, T.O. Weight 1557-1853 lbs, 8 flights, 43.8 hrs

Helios Prototype Flew to record 96,863 ft in Aug 2001



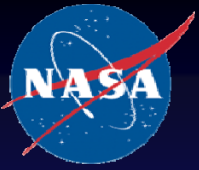
Helios with GH2/Air Fuel Cell



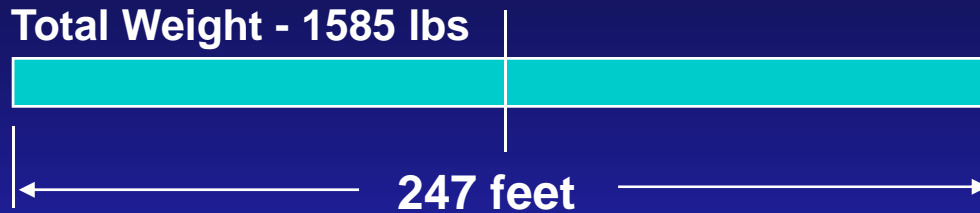
2003, added center pod fuel cell & wing tip GH2 tanks, T.O. Weight 2320 lbs, 3 flights, 15.4 hrs



~ 500 lbs heavier than ever flown



Evolution of the Long-Endurance Configuration



Helios Prototype (HP01)
Spanloader Configuration



Helios Prototype (HP01)
with Planned
Regenerative Fuel Cell System



Helios Prototype (HP03)
with Hydrogen - Air
Fuel Cell System
(Three Point Masses)

Helios 2003 Configuration

247' Wing Span

10 Electric Motordrives

64,000 Bi-Facial Solar Cells

6 Wing Panel Sections

Standard FTS Parachute

GH2/Air Fuel Cell
(520 lbs)

5 Landing Gear Pods

- Two 4400 psi Composite GH2 Fuel Tanks
- Capacity: 15 lbs GH2 each
- Weight: 165 lbs each

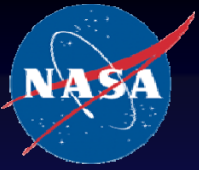
2003 Flight Operations

Hydrogen
Fill Station

Helios
Hangar

Ground Control
Station and
Trackers

Helios
Runway



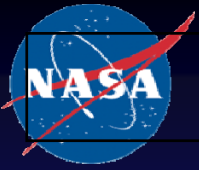
Flight Test Safety

➤ Project Plan, SSP, SSWG, PHL, PHA, SSHA, SHA, O&SHA, MP, RSOP, & RID

- Used previous hazard analyses as starting point for aircraft ops
- New challenges:
 - Fuel cell & GH2 tanks handling & storage
 - Multi-day mission (crew fatigue, crew rotation, crew qualifications, night landings, etc.)
 - Performed FMECA on the Fuel Cell System
 - Performed Facilities Hazard Analysis on the GH2 Fill Station
 - Performed Fault Tree Analysis on the FTS

➤ Flight Approval

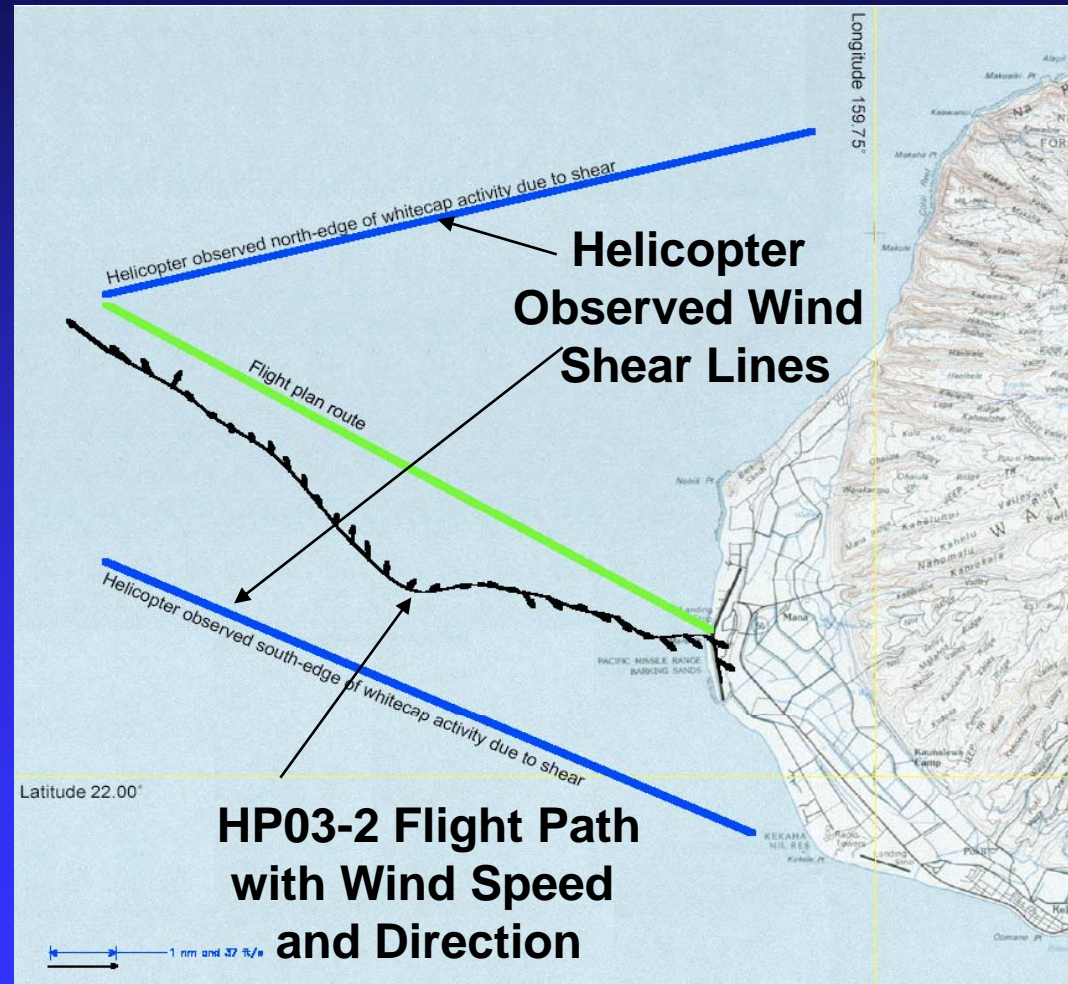
- TRRs, FRR, AFSRB, Tech Briefs
- Hazard Matrices & Accepted Risk List

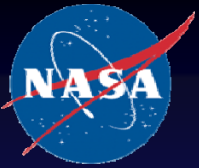


Helicopter Shear Line Observations

Northern Wind Shear Line

Southern Wind Shear Line





Helios 2003 Flight Activity

Project goal: Using the Solar/Fuel Cell configuration, fly greater than 14 hours at 50,000 feet.

➤ First Flight (5/15/03, straight line takeoff & landing; aka, high speed taxi)

- Mission dress rehearsal
- Verified aircraft dihedral compared to model predictions
- Successful flight

➤ Second Flight (6/7/03, took off at 8:45am, landed at 11:45pm)

- Demonstrated the readiness of the aircraft systems, fuel cell system, GCSs, flight support equipment, range support instrumentation, and procedures required for a multi-day flight
- A leak in the compressor system precluded full fuel cell operation at 50,000 feet
- Successful flight

➤ Third (mishap) Flight (6/26/03, took off at 8:45am)

- Conduct a single-day checkout flight and operate the fuel cell system for 1 hour at 50K
- Achieve rated flight power
- Develop confidence that the fuel cell can run all night



NASA
Dryden Flight Research Center







Photos Taken of HP03-2 26 June 2003



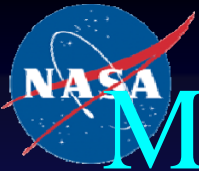
HP03-2 on Take-Off



HP03-2 with Normal Wing Dihedral

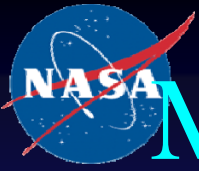


HP03-2 with Persistent High Wing Dihedral



Mishap Day Takeoff

- Add video of takeoff



Mishap Flight Events

➤ The aircraft experienced control problems approximately 30 minutes after takeoff while climbing through 2,900 feet...

- The aircraft entered a series of severe pitch oscillations, resulting in some failure of the secondary structure, and could no longer generate lift
- The aircraft impacted the water within the confines of the Pacific Missile Range Facility, approximately 10 miles west of the island of Kauai
- Except for loss of the aircraft, no property damage, environmental hazard, or personnel injury resulted from the mishap
- Approximately 70% of the aircraft (by weight) was recovered, including the two hydrogen fuel tanks



Photos Taken of HP03-2 Following Mishap



Falling to the Pacific



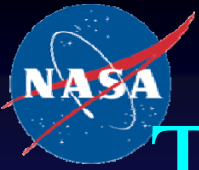
Helios Upon Impact with the Ocean



 **Navy Ship Providing Surveillance of Debris**

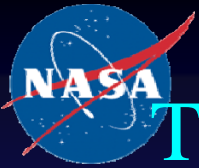


Close-Up of Floating Debris



The Helios Mishap Root Causes

- Lack of adequate analysis methods led to an inaccurate risk assessment of the effects of configuration changes leading to an inappropriate decision to fly an aircraft configuration highly sensitive to disturbances.
- Configuration changes to the aircraft, driven by programmatic and technological constraints, altered the aircraft from a spanloader to a highly point-loaded mass distribution on the same structure significantly reducing design robustness and margins of safety.



The Helios Mishap Recommendations

- ◆ Develop more advanced, multidisciplinary (structures, aeroelastic, aerodynamics, atmospheric, materials, propulsion, controls, etc) “time-domain” analysis methods appropriate to highly flexible, “morphing” vehicles.
- ◆ Develop ground-test procedures and techniques appropriate to this class of vehicle to validate new analysis methods and predictions.
- ◆ For highly complex projects, improve the technical insight using expertise available from all NASA Centers.
- ◆ Develop multidisciplinary (structures, aerodynamic, controls, etc) models, which can describe the nonlinear dynamic behavior of aircraft modifications or perform incremental flight-testing.
- ◆ Provide adequate resources to future programs for more incremental flight-testing when large configuration changes significantly deviate from the initial design concept.



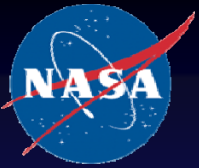
Contributing Factors and Recommendations (Continued)

- **The Review Process Was Not Structured to Adequately Identify the Risks Associated with this Vehicle Design, Especially as Design Margins Were Decreasing and Complexity Was Increasing**

Recommendation:

- ❖ **Enhance the Depth and Independence of Technical Participation in the Research Areas of this Class of Vehicle**

Take-Off and Landing of this Class of Vehicle Are High Pilot/Crew Workload Events with Significant Elevated Risk

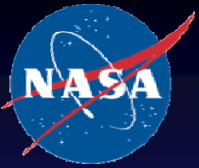


Contributing Factors and Recommendations (Continued)

- **Pilot Control Module/Interface Lacked Features that Would Afford the Pilot the Ability to Recognize and Mitigate an Impending Departure from Controlled Flight in a Timely Manner**

Recommendations:

- ❖ **Develop a Human/Vehicle System Interface to Better Conduct Research for this Class of Vehicle**
- ❖ **Improve the Pilot/Crew Displays to Allow Better Recognition and Situational Awareness of Slow Developing Hazardous Events**
- ❖ **Consider Adding Attitude Indicator to Improve Pilot's Situational Awareness**
- ❖ **Develop a Method to Measure Wing Dihedral in Real-Time with a Visual Display Available to the Test Crew**
- ❖ **Develop Manual and/or Automatic Techniques to Control Wing Dihedral in Flight**
- ❖ **Re-evaluate Providing Capability that Allows Pilot to Better Mitigate Unusual Flight Occurrences**



Contributing Factors and Recommendations (Continued)

- **Pre-Conditioning Associated with Previous Successful yet Infrequent Flights of this Class of Vehicle, Encounters with Benign Unstable Phugoid Responses, and Informal Crew Training Inhibited the Team's Ability to Predict, Identify, and React to the Impending Instability**

Recommendations:

- ❖ **Further Refine the Roles and Responsibilities of the Crewmembers to Improve Overall Team Response to Unexpected and Anticipated Emergency Conditions**
- ❖ **Refine Emergency Recognition Criteria to Improve Team Emergency Response**
- ❖ **Perform Simulations to Develop Recognition Criteria that Identify the Vehicle's Response Toward and During Instabilities**
- ❖ **Improve the Fidelity of Aircrew Simulations to Mitigate the Risks Associated with Landing and Take-Off**

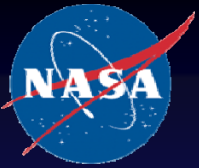


Significant Observations and Recommendations

Pilot and Crewmembers Failed to Recognize Instability in a Timely Manner

Recommendations:

- ❖ Develop Capability to Perform Simulations of the Vehicle's Response to Disturbances
- ❖ Improve Training Program and Use Simulations to Enhance Crew Resource Management During Normal, Emergency, and Unstable Flight Conditions
- ❖ Apply Crew Resource Management Techniques to Enhance Crew Ability for Identifying and Responding to Emergency and Unstable Flight Conditions

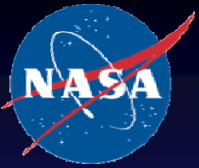


Significant Observations and Recommendations

- **Pilot Was Task-Saturated, Particularly During Mishap Event**

Recommendations:

- ❖ **Improve Interfaces to Alleviate Pilot Task-Saturation**
- ❖ **Re-Evaluate Pilot and Test Team Responsibilities to Optimize Task Management**
- ❖ **Extend Test Team Responsibilities to Include more Participatory Tasks with Provisions for Providing Advisory Status of Systems Operation**



Significant Observations and Recommendations

Aerospace Expert Onboard Photo Helicopter Not Linked to a Command and Control Frequency

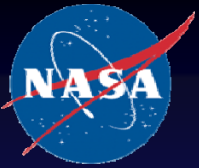
Recommendations:

- ❖ If Photo Helicopters Are Available, Consider Providing Capability for Direct Voice Communication Between the Helicopter and the Helios Pilot as Long as this Communication Does Not Appreciably Add to Helios Pilot Workload
- ❖ Consider the Chase Plane Concept of Operations to Improve Overall Test Team Management of Unexpected and Anticipated Emergency or Unstable Conditions



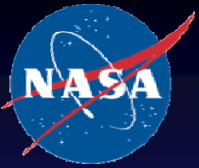
Lessons Learned Crew Training

- **Flight Crew Training Syllabus Development Could Benefit by Cross Talk and Visits to UAV Developers and Operators**
- **Lack of Crew Resource Management Techniques and Methodologies Can Significantly Handicap a Test Team's Ability to Successfully Negotiate Unanticipated Emergency or Unstable Conditions**



Lessons Learned: Assessing the Level of Risk

- Track programmatic decisions affecting design and assess the impact on mission success at each phase of the program
- While concentrating on “Single Point Failures” and “Single String Systems”, don’t overlook credible “Multiple Failure Scenarios”
- Monitor the cumulative effect of:
 - Slow increases in gross weight
 - Narrowing margins
 - Pressures to fly (schedule, budget, & manpower)
 - Range airspace availability
 - Range assets availability
 - Frequency management issues or conflicts



Q & A?

NASA has released a publicly available detailed report on the Helios Mishap which can be found at:

http://www.nasa.gov/pdf/64317main_helios.pdf