

Helios Prototype Vehicle Mishap: Technical Findings, Recommendations, and Lessons Learned

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

Presented

by

John Del Frate

Aerospace Control and Guidance Systems Committee Meeting No. 100

Outline

- Background
- Description of Mishap
- Observations Concerning the Mishap and Analysis Results
- Proximate and Root Causes
- Technical Recommendations and Lessons Learned
- Summary

MIB Members and Advisors

Chairperson: Thomas E. Noll, NASA Langley Research Center

Members: John M. Brown, National Oceanic and Atmospheric Admin
Marla E. Perez-Davis, NASA Glenn Research Center
Stephen D. Ishmael, NASA Dryden Flight Research Center
Geary C. Tiffany, NASA Ames Research Center

Ex-Officio: Matthew Gaier, NASA Headquarters

Advisers: Bart Henwood, NASA Dryden Flight Research Center
John Madura, NASA Kennedy Space Center
Ted Wierzbanowski, AeroVironment, Inc.

Background

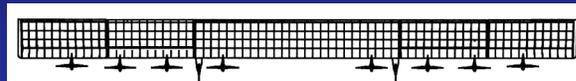
Evolution from the Pathfinder to the Helios

Pathfinder



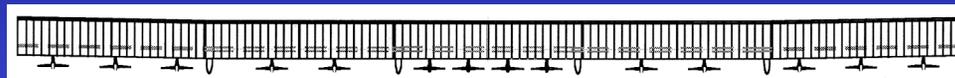
1981 - 1997

Pathfinder Plus



1998 - 2002

Centurion



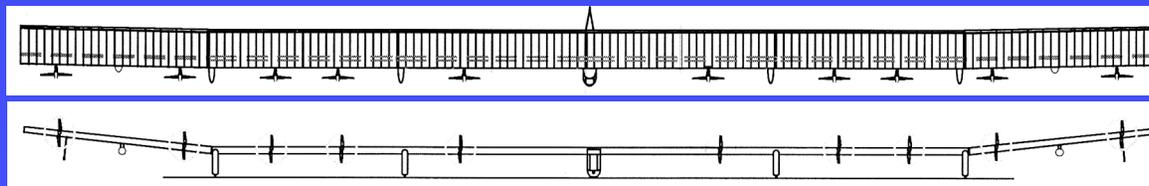
1998

Helios Prototype HP01 (High-Altitude Configuration)



1999 - 2001

Helios Prototype HP03 (Long-Endurance Configuration)



2003

Helios Prototype HP01 and HP03

- 1996: ERAST plans to build two flying vehicles
 - “Centurion” - high-altitude solar powered mission
 - “Helios” - long-endurance fuel cell/solar powered mission
- 1998: Development of Regenerative Fuel Cell System (RFCS) begins
- 1999: Under the constraint of a reduced budget, NASA and AV agree to build one airframe to demonstrate both ERAST missions
- “Centurion” is modified and renamed “Helios Prototype”
- 2001: NASA and AV agree to use consumable hydrogen-air Primary Fuel Cell System (PFCS) because of RFCS operational difficulties and schedules
- “Helios Prototype HP01” is modified for the PFCS and becomes the “Helios Prototype HP03”

Helios Prototype HP01 High-Altitude Configuration



On August 13, 2001 “Helios Prototype HP01”
reaches an altitude of 96,863 feet,
a world record for sustained horizontal flight by a winged aircraft

Evolution of the Long-Endurance Configuration

Total Weight - 1585 lbs



Helios Prototype (HP01)
spanloader configuration

Estimated

Total Weight - 1810 lbs



Helios Prototype (HP01)
with planned
regenerative fuel cell system

Total Weight - 2320 lbs



Helios Prototype (HP03)
with hydrogen - air
fuel cell system
(3 point masses)

Helios Prototype HP03

Long-Endurance Configuration

- Wing span 247 feet
- Wing chord – 8 feet
- Aspect Ratio – 31
- 10 2-HP (1.5 kw) motors
- 79 inch diameter propellers
- 72 trailing edge elevators
- Composite wing spar and ribs
- Wing wrapped with transparent plastic skin
- Aerodynamically shaped foam leading edge
- 6 41-foot wing panels
- No wing taper or sweep
- Maximum chord thickness – 11.5 inches
- 10 degree up sweep on outer wing panel



Helios Prototype HP03

1st Two Flights in 2003



Test Objectives:

- Verify the proper wing dihedral distribution
- Check preflight assembly and test procedures

Test Objectives:

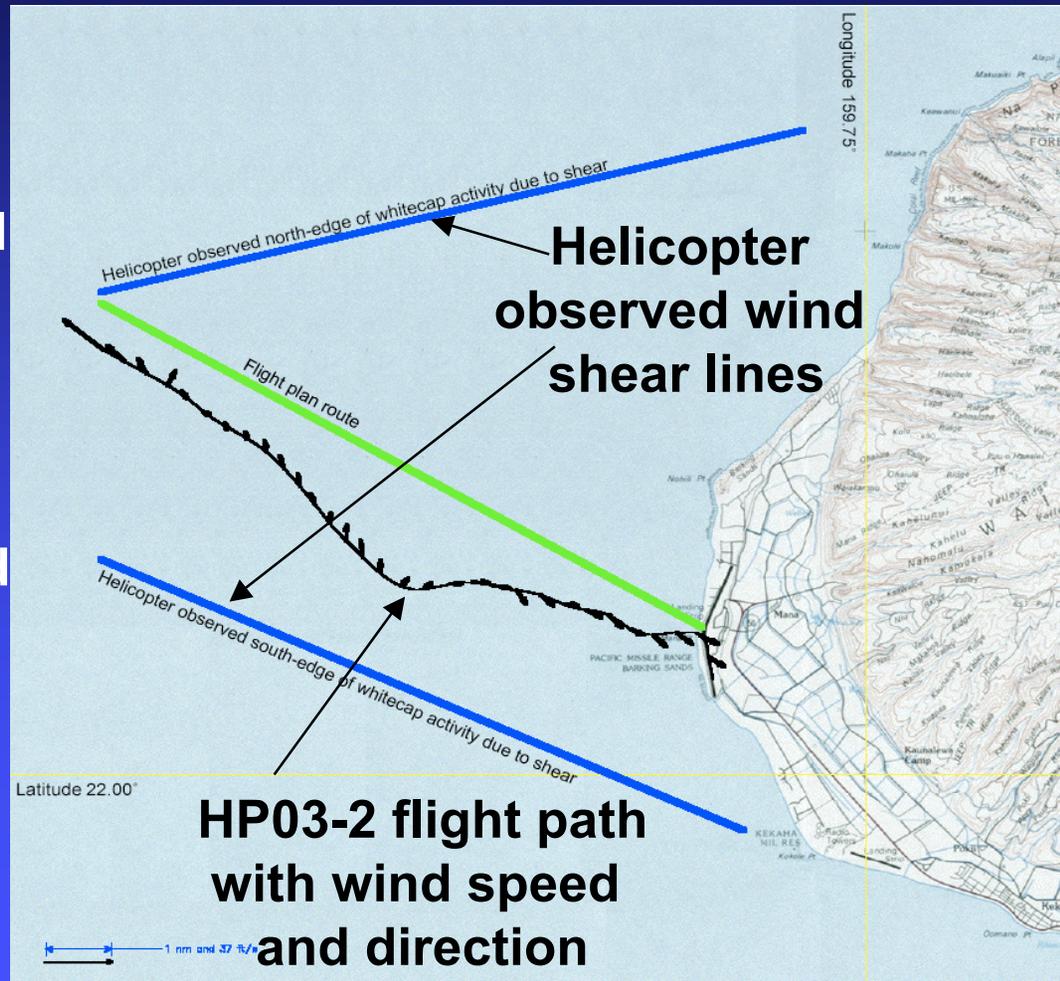
- Demonstrate the readiness of the aircraft systems, flight support equipment and instrumentation, and flight procedures
- Validate the handling and aeroelastic stability of the aircraft
- Demonstrate the operation of the fuel cell system
- Provide training for personnel to staff future multi-day flights

Description of Mishap

Turbulence Shear Line Observations

Northern wind shear line

Southern wind shear line



Photos Taken of HP03-2 June 26, 2003



HP03-2 on take-off



HP03-2 with normal wing dihedral



HP03-2 with persistent high wing dihedral

Description of Mishap

- On June 26, 2003 at approximately 10:35am at an altitude of about 2,800 feet, HP03-2 encountered turbulence associated with wind shear lines around the island of Kauai
- Turbulence initiated a persistent high wing dihedral causing an unstable pitch oscillation
- Airspeed excursions were around ± 2 ft/sec; main wing spar strain gauge reading 103% of limit load
- Following pilot procedures to reduce dihedral, wing dihedral decreased slightly, but then grew to over 30 feet
- Large airspeed fluctuations of about ± 10 ft/sec now observed, an indication the aircraft was experiencing large pitching motions
- Airspeed excursions began to double every cycle

Description of Mishap (Cont'd)

- Vehicle became oriented at extreme attitudes relative to the air stream (wing dihedral of about 40 feet with the airspeed nearing 90 ft/sec)
- High dynamic loads broke the right wing leading edge foam secondary structure near the hydrogen fuel tanks
- Solar cells and the wing skin began to rip off the upper surface of the wing resulting in loss of lift
- Vehicle entered a more severe attitude resulting in additional secondary structural failure
- Aircraft continued to come apart as it fell to the Pacific Ocean

Photos Taken of HP03-2 Following Mishap



Falling to the Pacific



Helios upon impact with the ocean

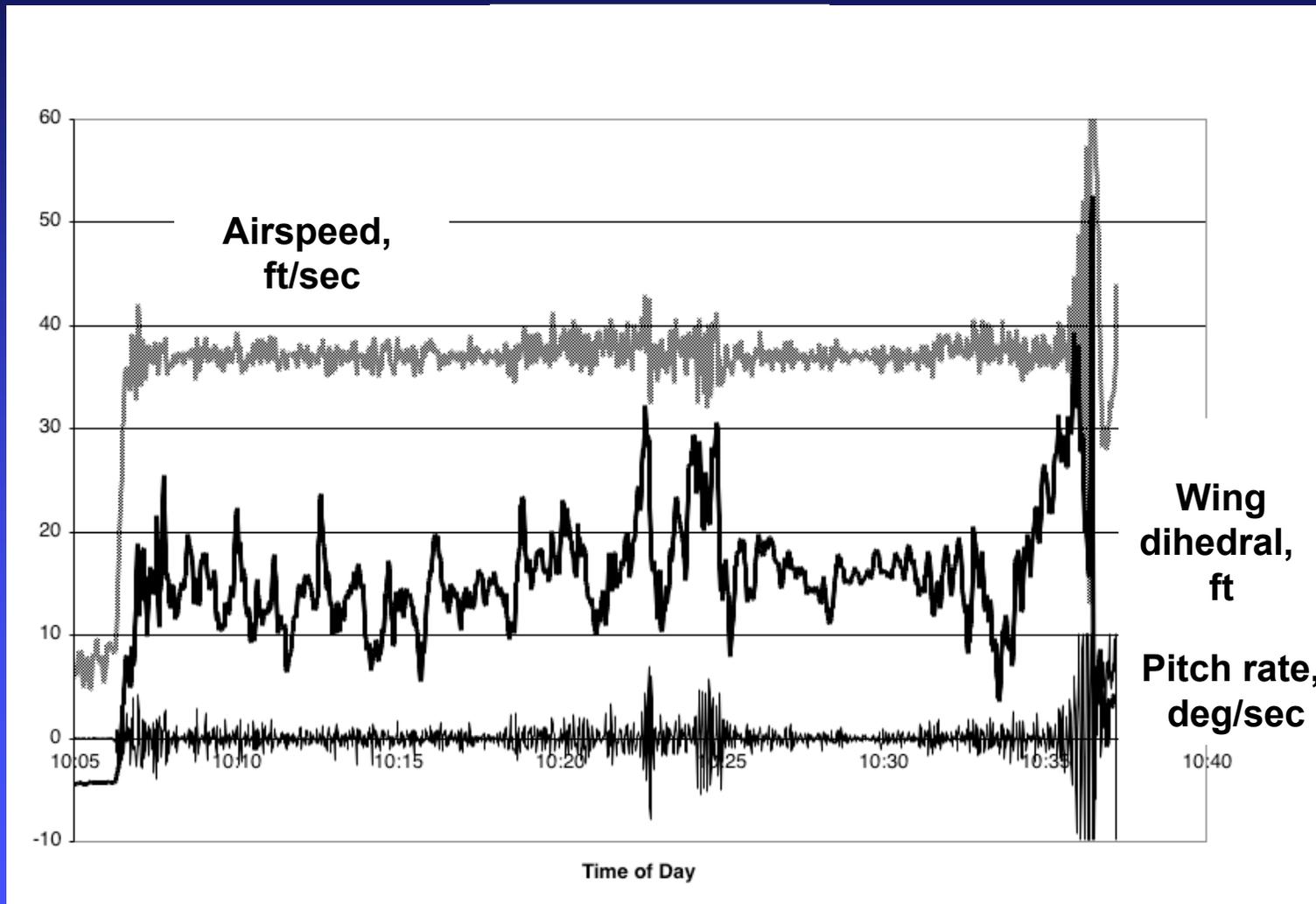


Surveillance of debris



Close-up of floating debris

HP03-2 Time History from Take-Off to Mishap

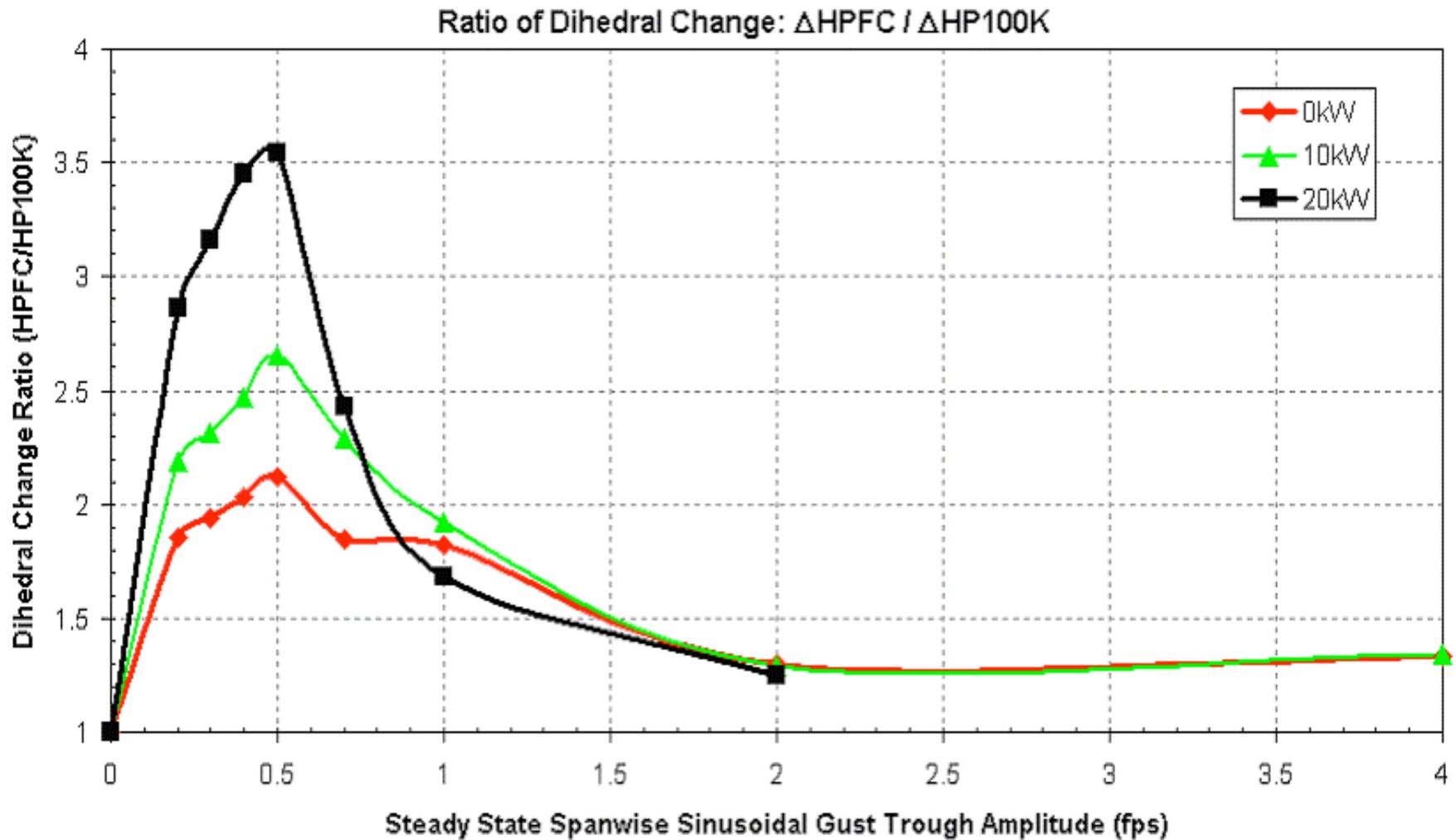


Observations Concerning Mishap and Analysis Results

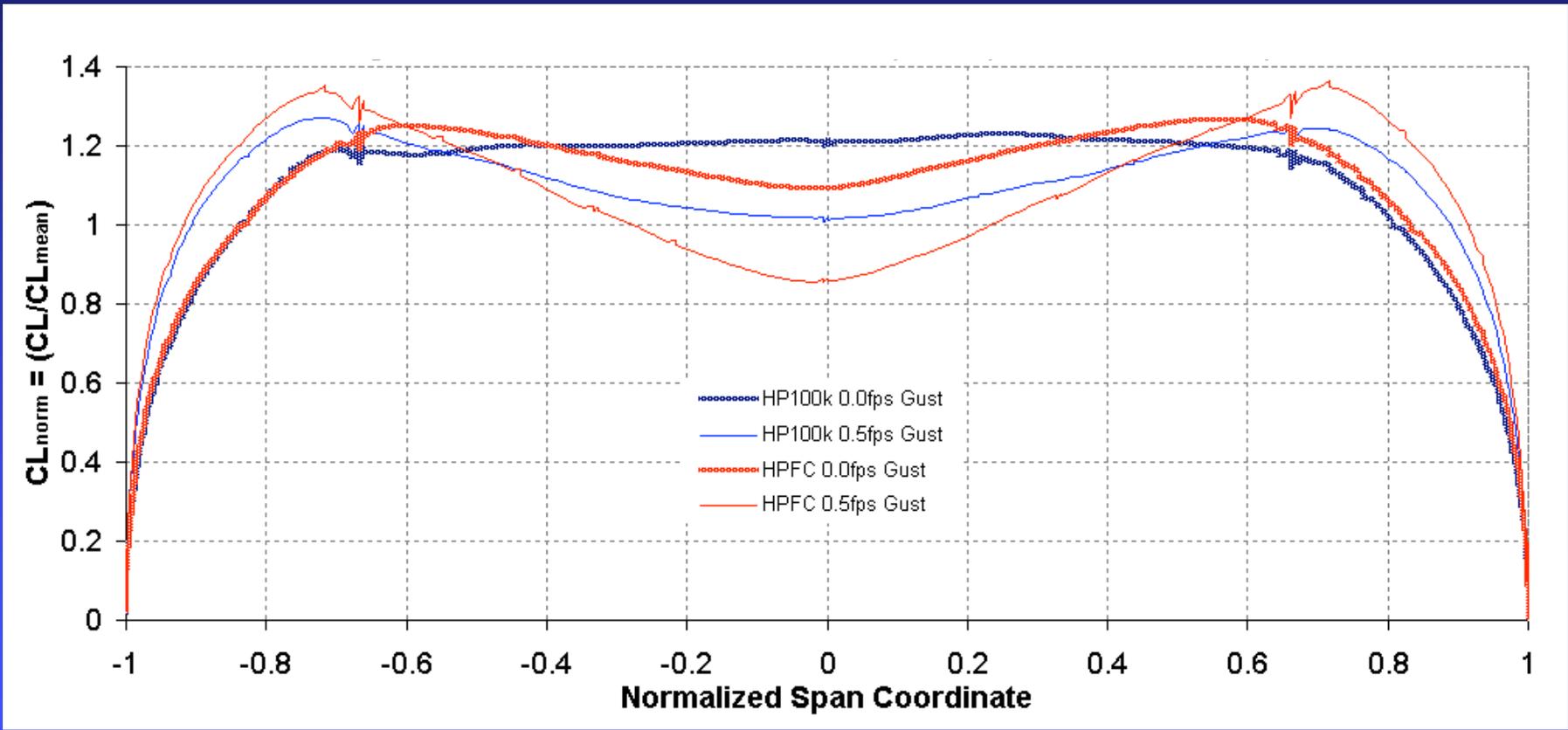
Surprises to Crew

- Strength of dihedral response to mild turbulence
- High persistent dihedral
- Wing not robust to returning to low dihedral
- Rapid divergence of pitch instability

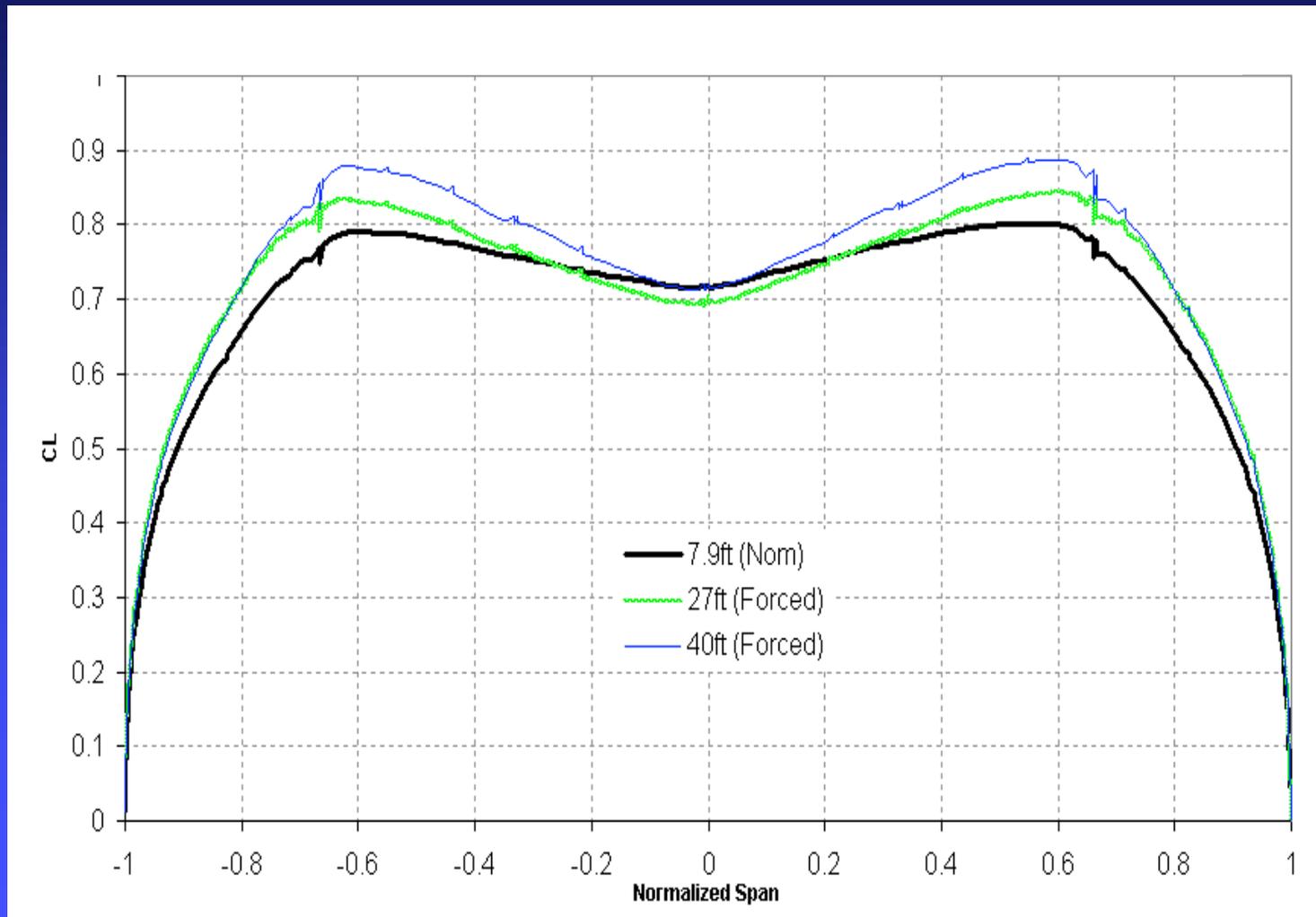
Increased Sensitivity to Small Gusts



Variation of Spanwise Lift Distribution with Gust Velocity



Spanwise Lift Distribution for Various Wing Dihedral



Proximate and Root Causes

Proximate Cause

Proximate Cause Definition

The event that occurred, including any condition that existed immediately before the undesired outcome, that directly resulted in its occurrence and, if eliminated or modified, would have prevented the undesired Outcome.

The proximate cause for the loss of the HP03-2 was the high dynamic pressure reached by the aircraft during the last cycle of the unstable pitch oscillation leading to failure of the vehicle's secondary structure.

Root Causes

Root Cause Definition

One of multiple factors (events, conditions, or organizational factors) that contributed to or created the proximate cause and subsequent undesired outcome and, if eliminated, or modified, would have prevented the undesired outcome.

- 1) Lack of adequate analysis methods led to an inaccurate risk assessment of the effects of the configuration changes
- 2) Configuration changes to the aircraft, 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

Technical Recommendations and Lessons Learned

Technical 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
- Develop multidisciplinary (structures, aerodynamic, controls, etc) models, which can describe the nonlinear dynamic behavior of aircraft modifications
- Provide for more incremental flight-testing when large configuration changes significantly deviate from the initial design concept
- Implement mitigations or hardware systems for returning a vehicle back into a safe flight envelope

Technical Recommendations (Cont'd)

- Develop a method to measure wing dihedral in real-time
- Develop manual and/or automatic techniques to control wing dihedral in flight
- Develop capability to perform simulations of the vehicle's response to disturbances
- Apply advanced atmospheric models that better predict conditions hazardous to this class of vehicle

Lessons Learned

- Including large point masses on this type of airframe should not be attempted without optimizing the design of the primary load carrying structure
- Measurement of wing dihedral in real-time is necessary with visual displays
- Procedure to control wing dihedral in flight is necessary
- Time domain design and analysis tools for examining the effects of disturbances on the behavior of highly flexible vehicles are a necessity
- Model fidelity/validation and time domain simulation, can significantly reduce technical risk where the complexity and nonlinear interaction is significant
- Using numerical simulation models, useful meteorological information can be obtained that highlights the regional weather peculiarities
- Design and analysis tools applicable to large, lightweight flexible wing aircraft require better space-time domain models of atmospheric disturbances

Summary

Summary Comments

- Instability associated with the Helios Prototype HP03-2 vehicle was a nonlinear stability and control problem involving complex interactions among the flexible structure, the unsteady aerodynamics, the flight control system, the environmental conditions, and vehicle flight dynamics
- Analysis tools and solution techniques were constrained by conventional and segmented linear methodologies that did not provide the proper level of complexity to understand the technology interactions on the vehicle's stability and control characteristics
- More advanced, multidisciplinary (structures, aeroelastic, aerodynamics, atmospheric, materials, propulsion, controls, etc) "time-domain" analysis methods appropriate to highly flexible, "morphing" vehicles are required
- Ground-test procedures and techniques appropriate to this class of vehicle are needed to validate new analysis methods and predictions