



**National
Transportation
Safety Board**

Gulfstream®
A GENERAL DYNAMICS COMPANY

**Crash During Test Flight
Gulfstream GVI (G650)
Roswell, NM
April 2, 2011**

6th European Flight Test Safety Workshop
Salzburg, Austria November 19, 2012

History of Flight

- Accident occurred on the 12th test run, which was flaps 10 one-engine-inoperative continued takeoff
- During previous 11 test runs, all target V_2 speeds were exceeded
- Takeoff rotation technique evolved to a continuously increasing pitch angle

History of Flight

- No pause at 9° pitch target, and pitch rate slowed through 9°
- Slight roll to right began 2 seconds before liftoff
- Airplane stalled below predicted stall AOA and stick shaker activation setting
- Pilots had no warning before stall

History of Flight

- PIC decreased pitch below stick shaker/PLI and applied corrective roll inputs
- Airplane remained stalled
- Stick shaker activated again, and PIC increased pitch and maintained full left control wheel and rudder
- Flight crew was unable to recover from stall or control right rolling moment

Airplane path



Right wing contact





Main landing gear

Concrete structure

ATC tower

7

Investigation

- Accident preflight briefing items included
 - Target pitch lowered from 10° to 9°
 - Pitch limit of 11°
- Test card did not specify how long pitch target applied or include pitch limit
- Test personnel had different understandings of target pitch and limit

Gulfstream's Flight Test Risk Management Program

- Gulfstream had an FAA-accepted risk management process
- Overseen by flight test safety review board (SRB) co-chaired by director of flight test and vice president of flight operations
- SRB review and approval required before start of developmental flight testing
- Did not specify when SRB must be reconvened during developmental testing

Uncommanded Roll Events

- Two uncommanded roll events occurred before accident flight, in November 2010 and March 2011
- SRB not reconvened
- Testing should have stopped because uncommanded roll events were unexpected test result

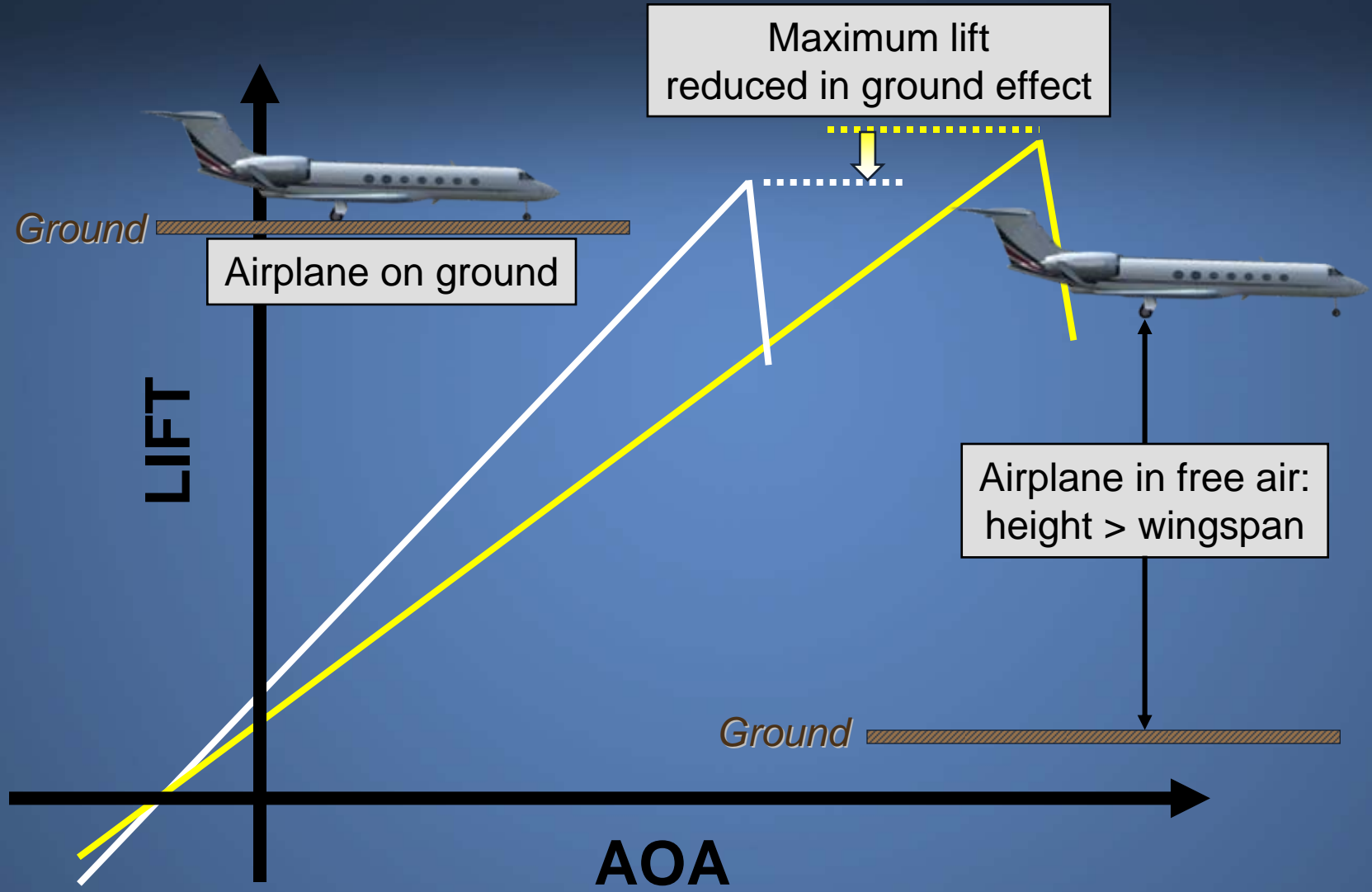
Uncommanded Roll Event (88)



Uncommanded Roll Event (132)

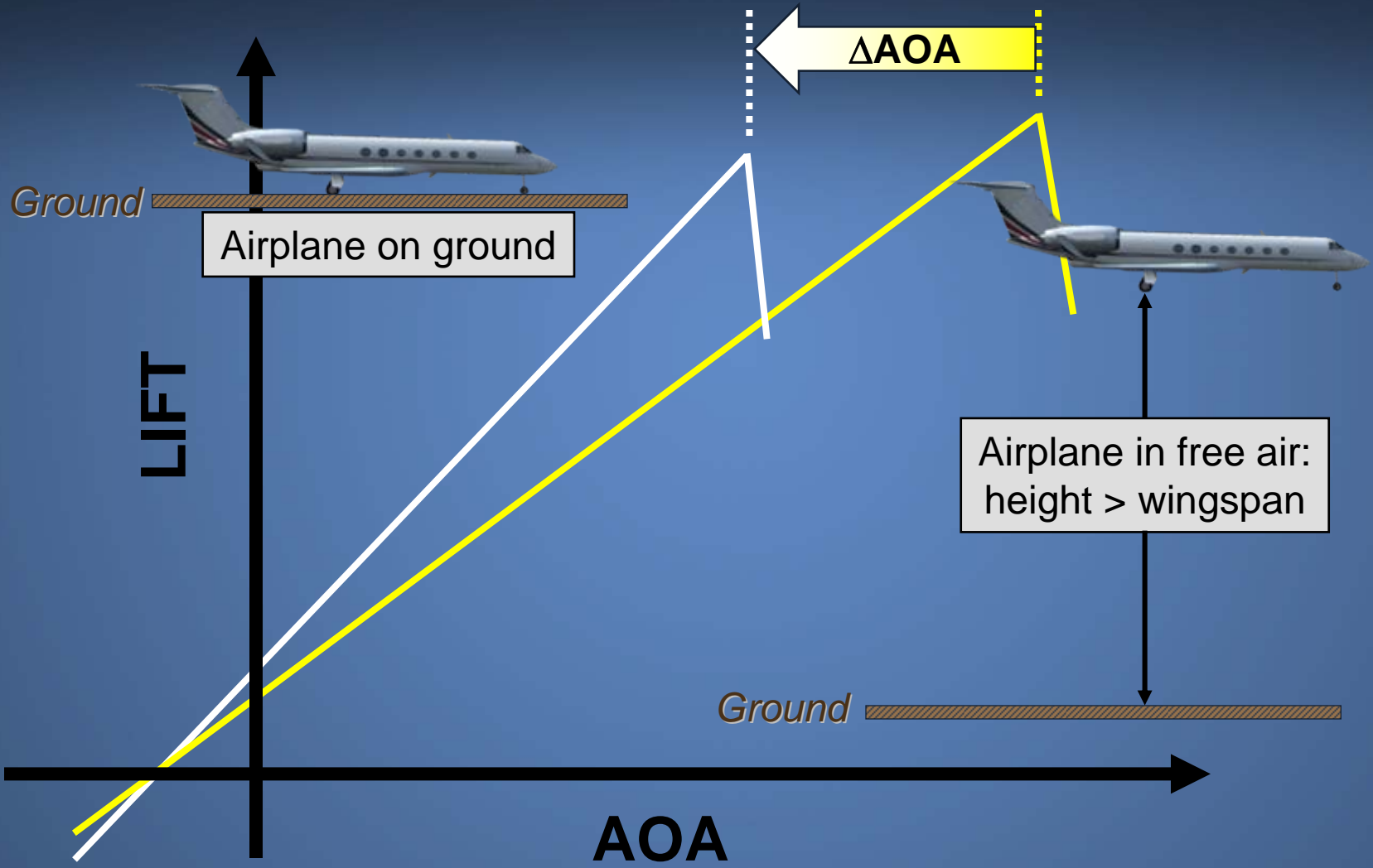


Ground Effect



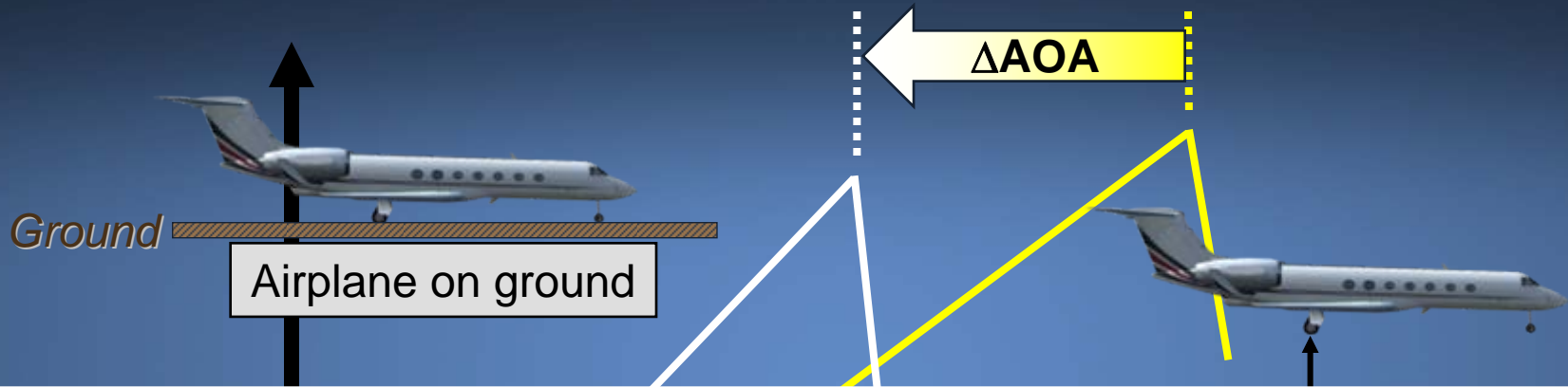
Ground Effect

Stall AOA
reduced in ground effect



Ground Effect

Stall AOA
reduced in ground effect



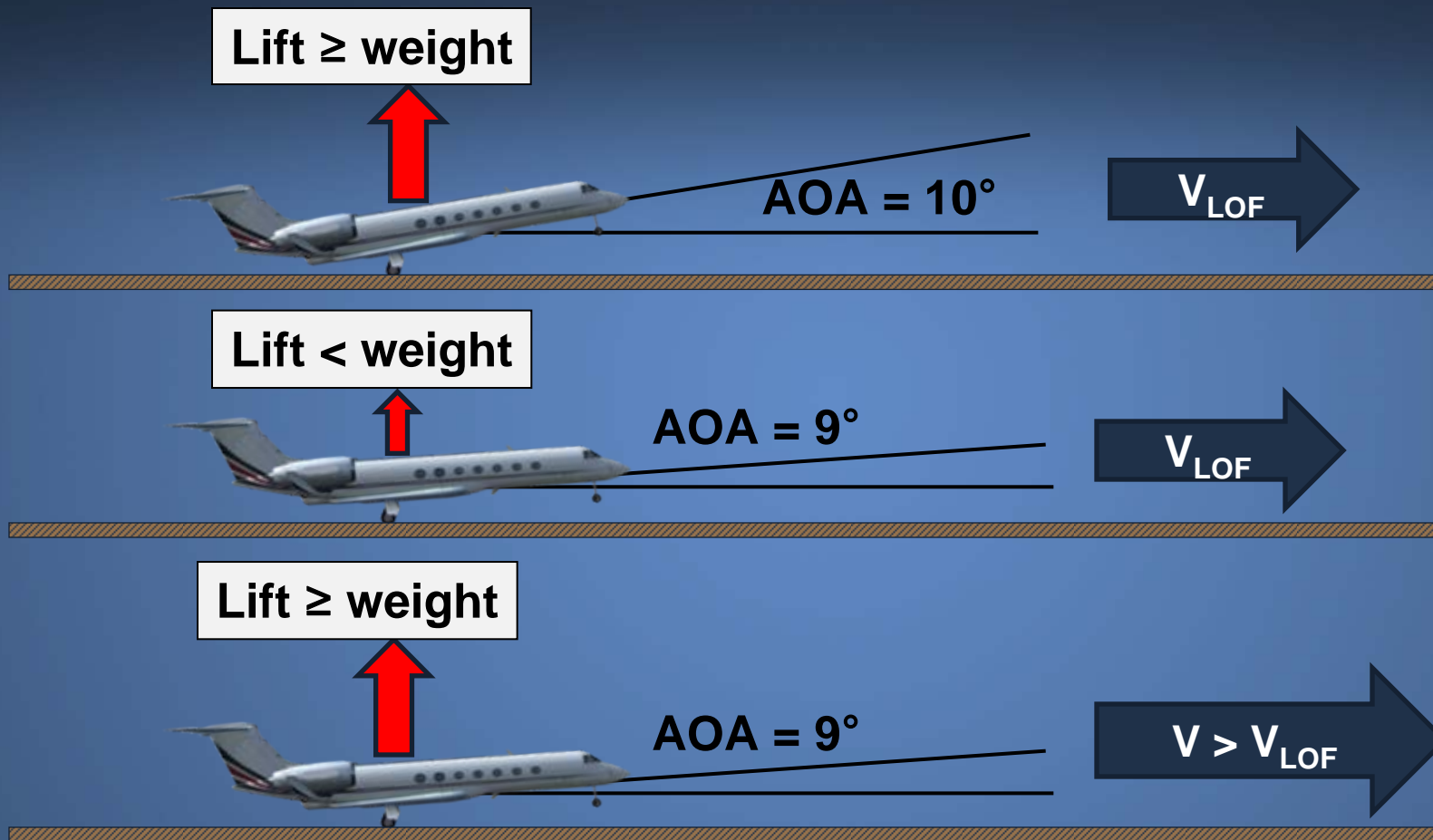
Estimated ΔAOA (from V_{MU} tests)	Actual ΔAOA (from postaccident CFD)	Difference
1.6°	3.25°	1.65°

RESULT: No warning before stall in ground effect

Missed opportunity: Actual ΔAOA indicated by two previous roll events

AOA

Change in Flaps 10 Target Pitch Angle



Reduction in pitch without increase in speed exacerbated V_2 overshoots

V_2 and Takeoff Distance

- Takeoff distance increases with higher V_2
- Achieving target V_2 necessary to satisfy takeoff distance guarantee
- No analysis of physics of G650 rotation to validate speeds or determine root cause of overshoots

Takeoff Rotation Techniques

- Gulfstream attempted to solve V_2 overshoot problem through takeoff rotation technique
- Pitch attitude for climb at V_2 greater than target pitch for takeoff rotation
- V_{35} reduced by reducing time to achieve climb pitch attitude
 - Achieve target pitch sooner (high rotation rate)
 - Increase pitch above target sooner

Probable Cause

An aerodynamic stall and subsequent uncommanded roll during a one-engine-inoperative takeoff flight test, which were the result of:

- (1) Gulfstream's failure to properly develop and validate takeoff speeds for the flight tests and recognize and correct the takeoff safety speed (V_2) error during previous G650 flight tests,
- (2) the G650 flight test team's persistent and increasingly aggressive attempts to achieve V_2 speeds that were erroneously low, and
- (3) Gulfstream's inadequate investigation of previous G650 uncommanded roll events, which indicated that the company's estimated stall angle of attack while the airplane was in ground effect was too high

Probable Cause - Contributing Factors

- Gulfstream's failure to effectively manage the G650 flight test program by pursuing an aggressive program schedule without ensuring that the roles and responsibilities of team members had been appropriately defined and implemented
- Engineering processes had received sufficient technical planning and oversight
- Potential hazards had been fully identified
- Appropriate risk controls had been implemented and were functioning as intended



Recommendations

Ten recommendations issued as a result of the accident investigation

- Gulfstream received two
- FTSC received three
- FAA received five



Human Performance and Organizational Factors

Liftoff (09:33:50.6)



SIMULATION PAUSED - Press P to continue.

PLAYBACK [10 / 19 seconds]



First Stick Shaker Activation (09:33:52.3)



Second Stick Shaker Activation (09:33:53.6)



Airplane Departing Runway (09:33:54.7)



Flight Crew Response to Stall and Roll

- PIC's column push after first stick shaker activation was appropriate
- Pitch was reduced below PLI, and stick shaker activation ceased
- Airplane remained in a stall that overpowered lateral controls
- PIC was likely confused by airplane's response

Flight Crew Response to Stall and Roll

- PIC's column pull after second stick shaker activation was inappropriate
- Airplane was departing runway
- Conflicting cues, stress, and time pressure likely influenced PIC's response
- Recovery after second stick shaker activation was highly unlikely

G650 Program Management

- Technical planning and oversight
- Program scheduling
- Safety risk management



G650 Program Management: Technical Planning and Oversight

- Company manual separated duties of test planning and conduct from analysis and reporting
- Duty separation intended to facilitate timely and accurate task completion
- Duties were combined during G650 field performance testing
- FTE1 did not finalize analysis of key data in time to facilitate refinement of takeoff speeds

G650 Program Management: Technical Planning and Oversight

- Inadequate control gates
- Inadequate validation processes
 - Independent reviews of speed calculations
 - Physics-based dynamic analysis/simulation

G650 Program Management: Technical Planning and Oversight

- Inadequate development and implementation of on-site team member roles
- During accident flight, FTE2's responsibilities were unclear
- No engineer was assigned responsibility to monitor safety-related parameters compared with briefed limits

G650 Program Management: Technical Planning and Oversight

To FTSC and FAA:

Work in collaboration to, develop and issue flight test operating guidance for manufacturers that addresses the deficiencies documented in this report regarding flight test operating policies and procedures and their implementation, and encourage manufacturers to conduct flight test operations in accordance with the guidance.

G650 Program Management: Program Schedule

- Ambitious schedule
- Frequent delays
- Unachievable deadlines
- Schedule pressure can lead to decision biases, shortcuts, and errors

G650 Program Management: Program Schedule

- Organizational processes can counterbalance schedule pressure
- Gulfstream lacked adequate technical oversight and safety management
- Schedule pressure likely played role in several key errors

G650 Program Management: Program Schedule

Schedule pressure likely influenced

- Decision to experiment with pilot technique rather than thoroughly analyze V_2 overshoots
- Decision to change target pitch without analyzing effect on takeoff speeds
- Decision to create pitch limit without adequately defining limit or including it on test cards
- Acceptance of oversimplified and inaccurate explanations for previous incidents

G650 Program Management: Safety Management

- Gulfstream had an FAA-accepted flight test risk assessment program
- No formal identification of stall-related events as potential hazard during continued takeoff testing
- Gulfstream's program lacking in area of safety assurance
- Previous stall-related events not adequately investigated

G650 Program Management: Safety Management

- FAA flight test safety guidance presented in terms specific to FAA's organizational structure
- FAA and International Civil Aviation Organization guidance not tailored to unique aspects of flight test (nonroutine, high-risk operations)

G650 Program Management: Safety Management

To FTSC and FAA:

Work together to develop and issue flight test safety program guidelines based on best practices in aviation safety management.

To FAA:

After the FTSC has issued flight test safety program guidelines, include these guidelines in the next revision of FAA Order 4040.26, Aircraft Certification Service Flight Test Risk Management Program.

Recommendations to Gulfstream

To Gulfstream:

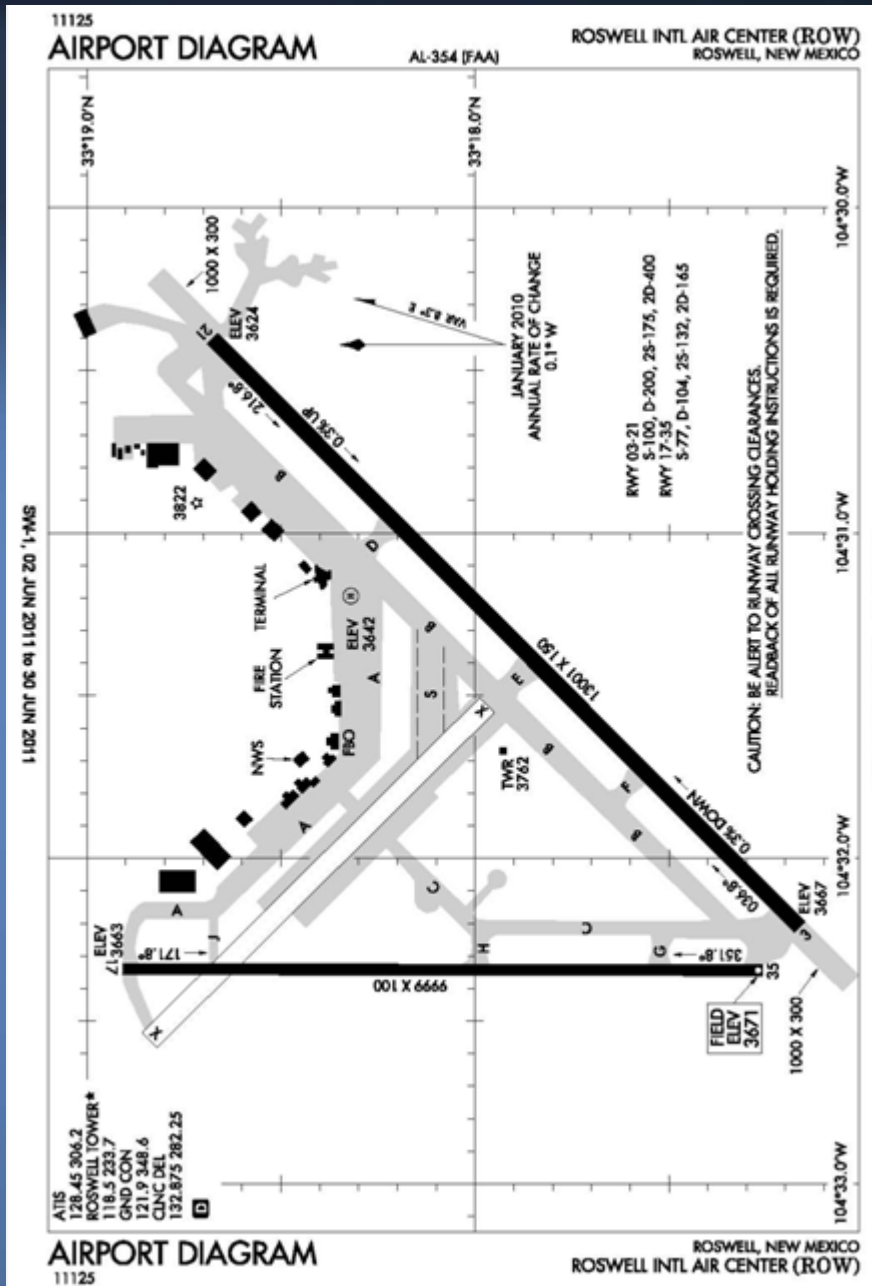
Commission an audit by qualified independent safety experts, before the start of the next major certification flight test program, to evaluate the company's flight test safety management system, with special attention given to the areas of weakness identified in this report, and address all areas of concern identified in the audit.

Provide information about the lessons learned from the implementation of its flight test safety management system to interested manufacturers, flight test industry groups, and other appropriate parties.



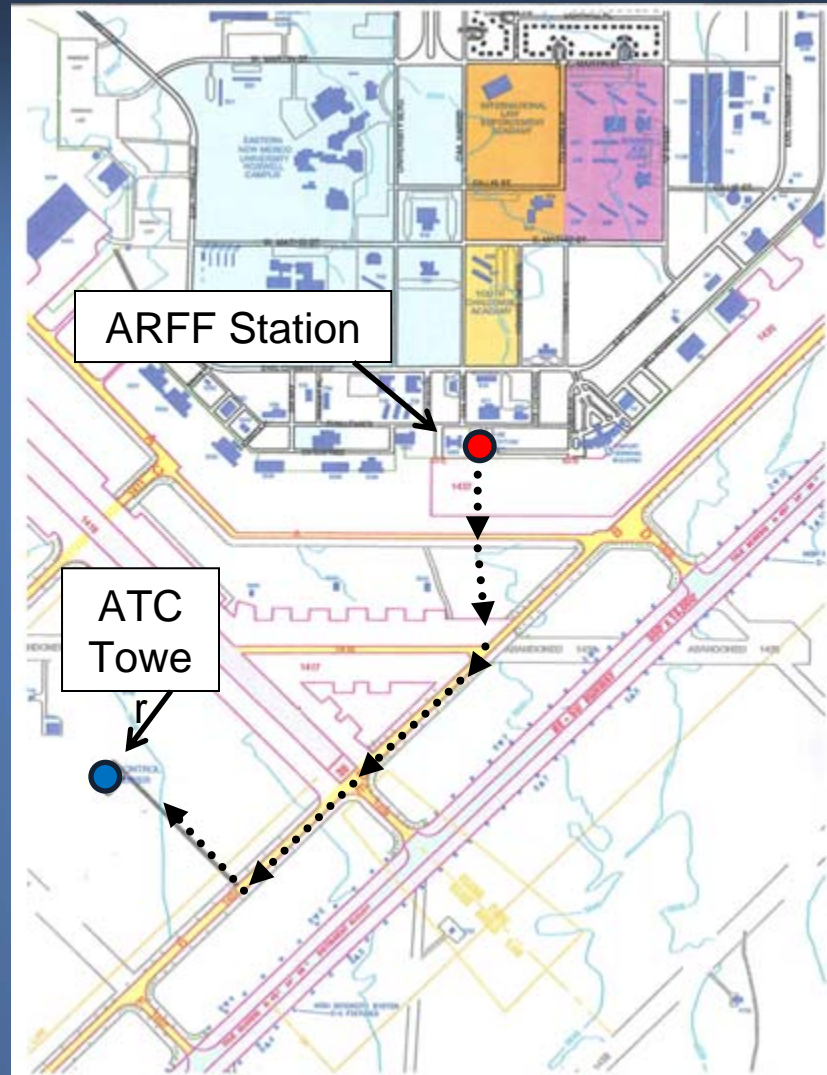
Survival Factors

ROW Airport Diagram



SWA-1, 02 JUN 2011 to 30 JUN 2011

ARFF Response Route





Time of photograph was 15:34:15 UTC.



Time of photograph was 15:37:22 UTC



Time of photograph was 15:38:17 UTC.

Recommendations from Final NTSB Report

- Inform 14 Code of Federal Regulations Part 139 airports that currently have (or may have in the future) flight test activity of the importance of advance coordination of high-risk flight tests with flight test operators to ensure that adequate aircraft rescue and firefighting resources are available to provide increased readiness during known high-risk flight tests.
- Encourage members to provide notice of and coordinate high-risk flight tests with airport operations and aircraft rescue and firefighting personnel.



Additional Recommendations Issued in Separate Letter

- Determine whether 14 CFR Part 139 airports have sufficient and qualified operations personnel on duty at the airport during all scheduled air carrier operations, and direct airports without such staffing to implement actions to meet the personnel requirements of section 139.303.
- Amend Order 7210.3V to ensure that, when practicable, emergency response notification telephone or communication lines are recorded, with valid time references, in ATC facilities.



Gulfstream Lessons Learned

6002 Flight 153 LOC Event Distilled

- **V-speed development and validation**

- Assumptions, Methods and CFR's
- Process / Review / Approval
- Results: Data Analysis and Matching



- **In ground effect (IGE) / rotation characteristics**

- Wing Configuration (Clean, No Slats)
- Tail Control Power
- Stall Warning
- Delta AOA / CL max

- **Test team persistence**

- Previous Roll Off Events
- Technique Experimentation
- Control Gates
- Data Review Process

FTSC “Call to Action”

- **Flight test operating guidance**

- FAA Collaboration
- Procedures / Policy
- Test Team Implementation
- OEM Test Community Compliance

- **Flight test safety programs**

- FAA Collaboration
- Best Practices in FT SMS
- OEM Test Community Participation

- **Test site preparation**

- Airport Operations Notification
- Fire / Rescue Coordination

LOC – Planning / Threat Challenges

- **Planning awareness**

- Flight Regime
- Proximity to Ground
- Quality of Predictions

- **Recognition**

- Element of Surprise
 - Mechanical or Aero?
 - Non-Traditional Cues – Buffet, Roll, Control Input
- Pilot Flying/Pilot Monitoring/TM Roles & Responsibilities

- **Response**

- Planned & Briefed
- Instinctive
- Intuitive (as possible)
- Practiced

LOC - Planning Challenges

- **Modeling and simulation**

- Limitations
- Data Validation
- Review Process

- **Test planning**

- Procedure vs. Technique
- Test Hazard(s) Analysis
- Perf Goals vs. Certification Requirements

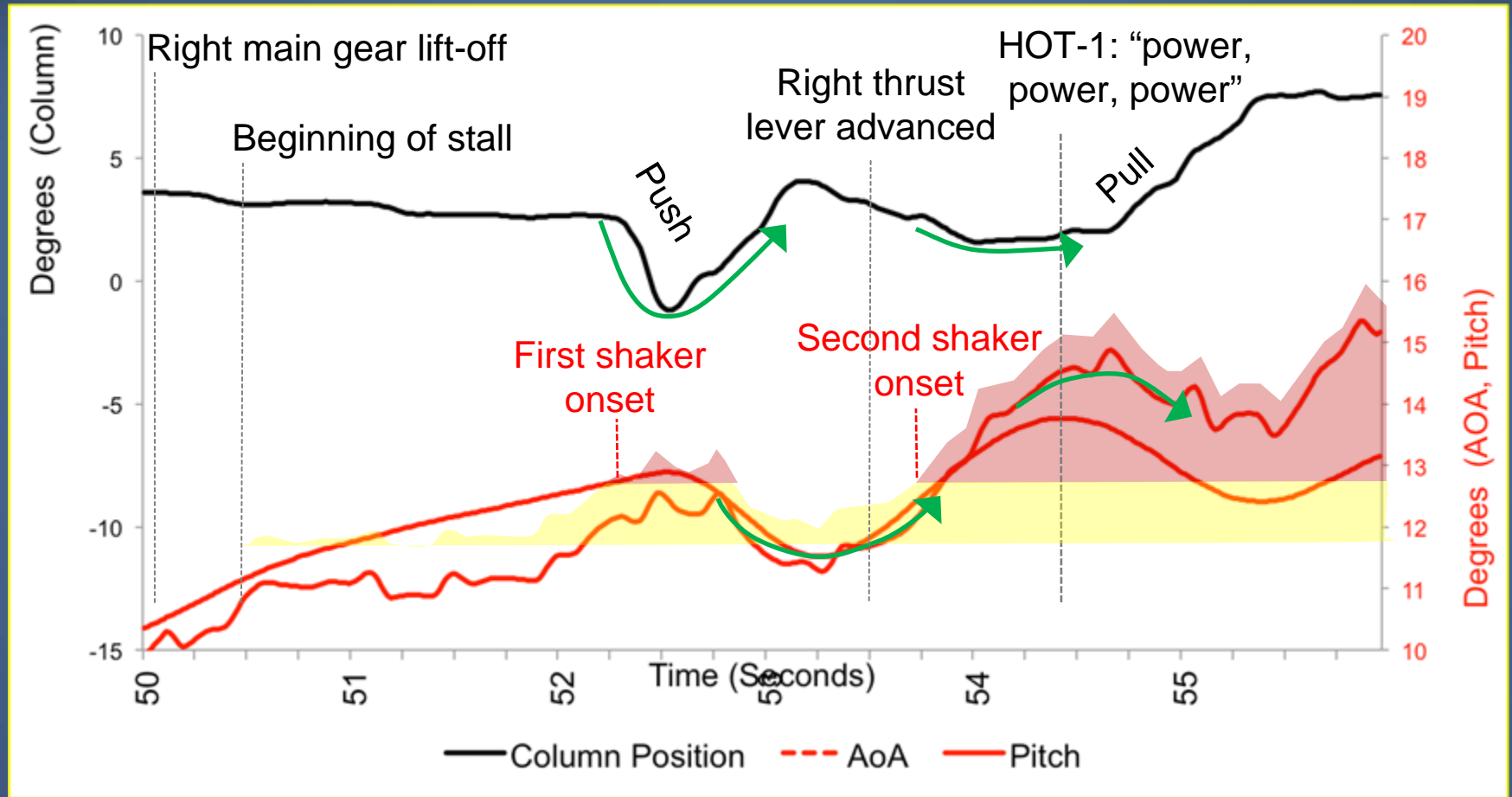
- **Test execution**

- Build Up / Build Down Methods
- Tolerances
- Abort Criteria



Questions??

PIC Response to the Stall and Roll



Comparison of G550 & G650 takeoff speed ratios (flaps 10)

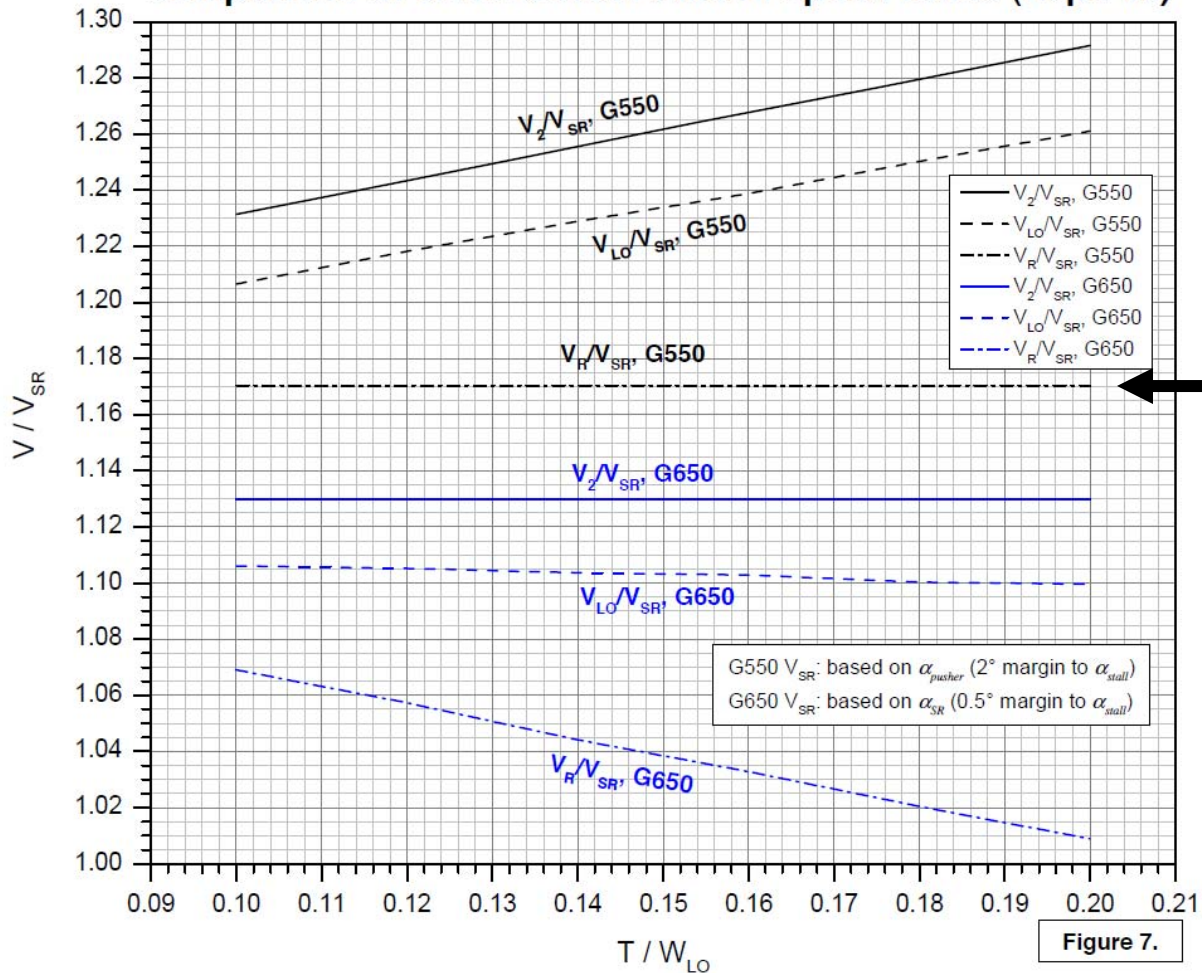


Figure 7.

G550 Decrements Applied to Lower G650 V2 Targets

G550

G650