X-57 Piloted Simulation Discussion

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X-57 Flight Test – Lessons Learned

- Value of a simulator
  - Energy assessment, emergencies, peer review, and human machine interface development for electrical propulsion systems – and (in-lieu of flights)
- Mod III was not a suitable build-up to Mod-IV due to numerous risks
- Mod IV DiTTo procedures met both power limitations & safety concerns
- The HL “blown-lift” design enabled approach speeds comparable to Mod II
- The Mod III/IV stall characteristics were safe and predictable (simulator)
- X-57’s all experimental propulsor design required the ability to glide to a safe approach and landing – with or without the CM, HL, or battery systems
- Edwards (Roger’s lakebed) is ideal for first flights of vehicles like the X-57
  - Long runway, ample landing options, available airspace, and LOS telemetry
- Method for takeoff – most critical phase of flight

X-57 Flight Test
Overall Objectives

- Overall objectives
  - Safely recover the aircraft after any failure
  - Efficiently acquire data
- Constraints
  - All experimental propulsive system – crew-rated
  - Single pilot and no parachutes for either the pilot or the aircraft
  - This particular airframe has not flown before
- Advantages
  - Telemetry, long runway and lakebeds,
    Battery system PPR proven, CTOL (fixed wing)

Simulator

- Close to flying X-57 – a flight test laboratory
  - Flight test from the P2006T; cockpit design of the actual aircraft
- Results
  - HMI – how to control the HL system (example)
  - What-ifs for emergencies – develop appropriate procedures
  - Identify risks and allow an independent review of those risks
  - Build efficient plans for test flights
  - Training is a primary mitigation for many of the risks

Mod III challenges (as compared to Mod II)

- Reduced wing area (42%) & increased motor loss asymmetry moment
  - Increased Vs and Vy; lower Rc_{Vy}; higher Vmca speeds
  - Touchdown attitude < 7 deg bank to avoid prop strike
  - Reduction in wing surface area to horizontal tail ratio
    - Reduced pitch damping – potential PIO
- Results
  - Must have dry lakebeds after initial takeoff
  - Immediate action procedure for motor loss on takeoff
  - Higher speed “low L/D” landing approaches –
- *Conclusion – risk of aircraft loss on takeoff exceeds the value of operating the HL system initially at altitude*

Mod III Takeoff With Cruise Motor Failure

Mod IV DiTTO

- With HL (Mod IV) using DiTTo (Distributed Thrust Takeoff, HL at fixed rpm):
  - CM prop levers set to 1700 RPM, Torque levers set to 100%, HL with fixed RPM
    - CM power 63% of full power
- Results:
  - DiTTo reduces total battery demand to 210-270 Amps (300 Amps is the limit)
  - Lowers Vs (blown lift), Vappr, and Vy;
  - Increases Rc_{Vy} – thrust from both CM & HL
    - Useable lakebeds not required
  - Reduces CM loss asymmetric moment
    - Reduces Vmca
  - Eliminates immediate action procedure for cruise motor loss on takeoff
    - HL and CMs are separate sources of thrust- No failure common modes (besides batteries)

	Mod II	Mod III	Mod IV DiTTO
Vs1 (kts)	60	80	70
Vy (kts)	72	96	84
Rc_{Vy} (fpm)	650	300	900
Vmca (kts)	59	86	73
Vappr (kts)	75	94	75

Mod IV DiTTo With Cruise Motor Failure

Glide and High-Key / Low-Key general approach

- Flight procedures planned to have a total propulsion loss option and still land on a primary runway or usable lakebed
  - Any sub-system fault would force a return to base (RTB)
  - Normal recoveries will plan to recover via High Key / Low Key pattern - not a long straight-in
  - Distance from runways < glide range to low key of a runway or usable lakebed
    - High key – 2200'AGL; Low key – 1200'AGL (added gear drag)
      - Gear takes 15-20 sec to raise/lower
    - 500'/nm descent clean – similar to the T-34
      - Glide descents practiced in the rental Tecnam and simulator
    - Most flight test altitudes – 6000' MSL
    - Distance from runways adjusted for winds of the day
    - Allows data runs of ~8 mins within the Edwards AFB class D airspace

Mod III/IV landing approach considerations

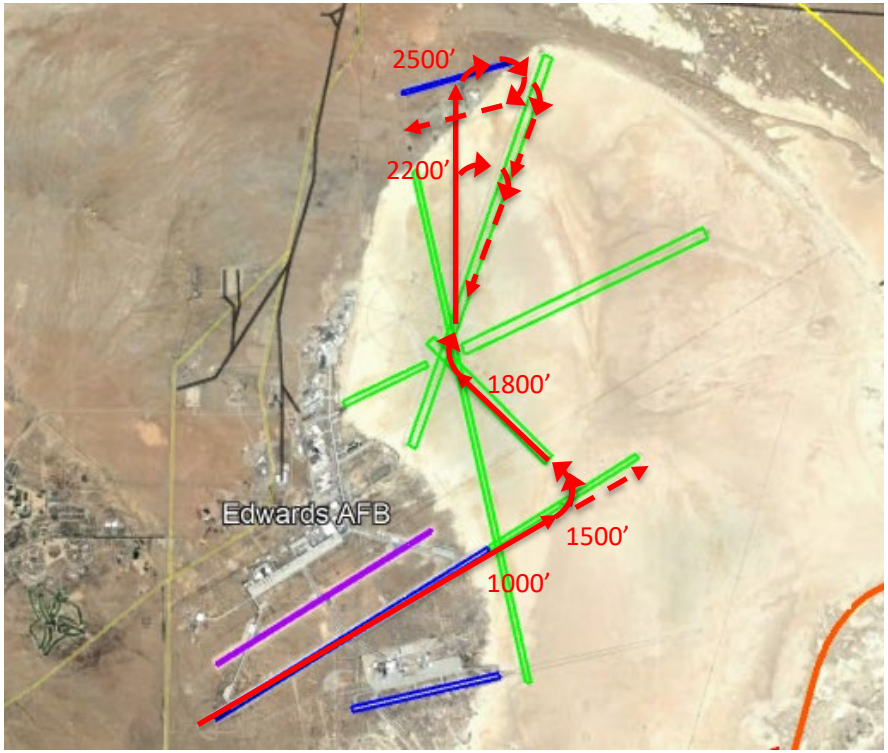
- Without HL (Mod III) and CMs at Idle, landing flare out of 1500’/min (glide) will probably require 1.3 Vs minimum for glide speed = 115 Kt (no flap), 104 kt (T/O flap) – think “low L/D”
  - Probably lose 15-20 knots flaring the aircraft to zero sink rate from 1500’/min
- With HL (Mod IV), the flare descent angle at 75 knots is close to 3 deg descent path
  - Maintain higher Mod III speeds during recovery turns
  - On final, HL with Airspeed Mode is selected
  - CM torque settings are idle or slightly regen to maintain a 3 deg glidepath
    - V_{appr} (75 kts) - Gear down and full flaps – HL in Airspeed Mode
  - After touchdown, HL is deselected with the yoke switch

X-57 SOC RTB Guidelines

- Plan recovery altitude for a hi-key/ low-key profile at idle torque
- Plan SOC for RTB to allow a 2 min orbit at low key for traffic
  - As opposed to reserving power for a go-around and another pattern
    - Go-around is not excluded but may have power limitations due to lower battery voltages and will result in a higher Joker/Bingo SoC
- Declare emergency fuel for priority or land at South Base if necessary

Mod IV Approach with Full Power Failure

Mod IV - Emergency Operations
Takeoff options – Lakebed dependent



Typical takeoff plan with usable lakebeds:

Color Code:

Primary runways

- Main base 05R/23L, 05L/23R
- South Base 07/25, - North Base 06/24
- Lakebeds

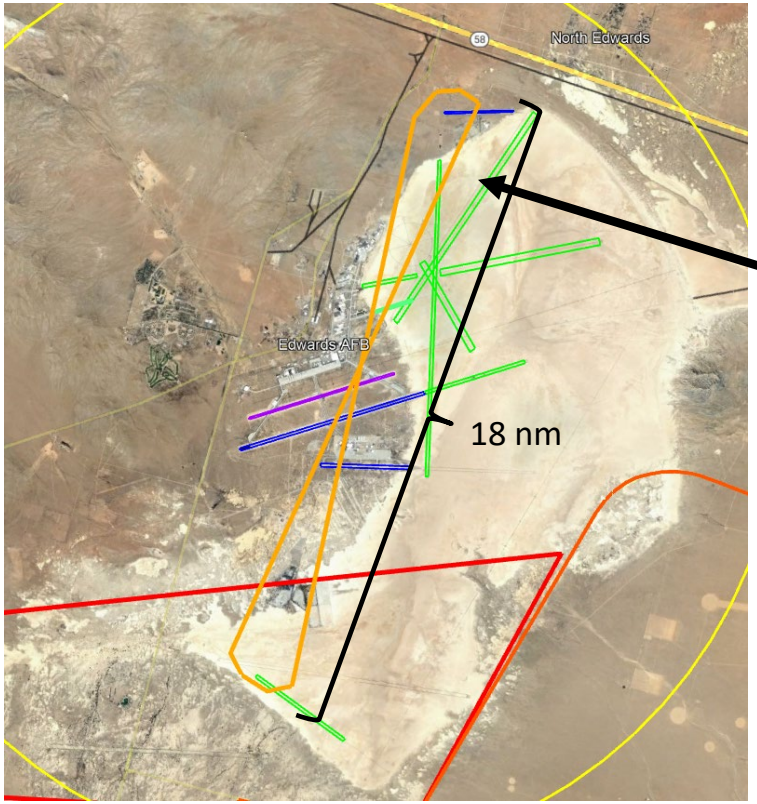
Depicted AGL altitudes based upon simulator data

- Solid red shows climb path
- Dashed red shows emergency landing options
- *Considerably higher altitudes with Mod IV*

Note: All altitudes are AGL

Mod II - Emergency Operations
Glide and High-Key / Low-Key general approach

Color code:
Primary runways
- Main base 05R/23L
- South Base 07/25
- North Base 06/24
Emergency runways
- 05L/23R
Lakebeds

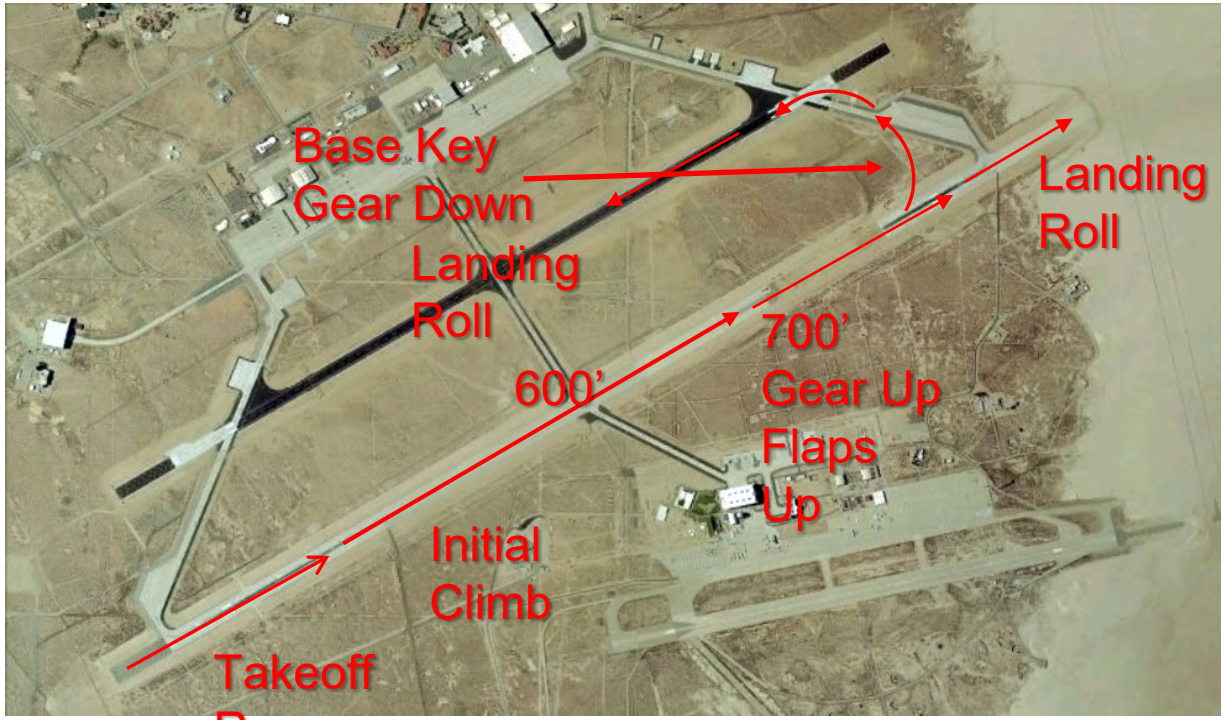


Typical flight path
- Allows 18 nm data runs (~10 minutes)
- Allows glide to low-key to primary runways starting from a 6000’ MSL flight test altitude

Mod IV - Emergency Operations Takeoff Options

- Takeoffs are the most critical phase of flight
  - Takeoff Runway 05R over usable lakebeds (preferred) ***or***
  - Takeoff 05R/23L with climb-out in a flameout pattern (unusable lakebeds)
    - The maximum altitude on takeoff and still stop straight-ahead on the remaining runway (including under-run/over-runs) is ~700’ (no-wind)
      - Challenging - requires >97 KIAS descent, flare, and stop in remaining runway
    - 700’ is also a minimum low-key altitude to the parallel runway
    - Departure emergency plan: (for a possible total propulsion failure, gear is left down until 700’)
      - Up to 500’, abort straight-ahead for any anomaly
      - 500’-700’, abort straight ahead for battery emergency or complete propulsion loss
      - At 700’, raise gear/flaps and reduce power to MCT, accel to 97KIAS, turn off HL (pilot discretion)
      - Maintain power and turn as required to land on 05L/23R (opposite direction) or back on 05R/23L (same direction)
      - Until reaching hi-key, the low-key runway may be behind you!

Mod IV - Emergency Operations
Takeoff options – unusable lakebed runways



HL power is used as necessary to make a safe landing

Mod IV Takeoff with Cruise Motor Failure at 700 ft

Questions?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