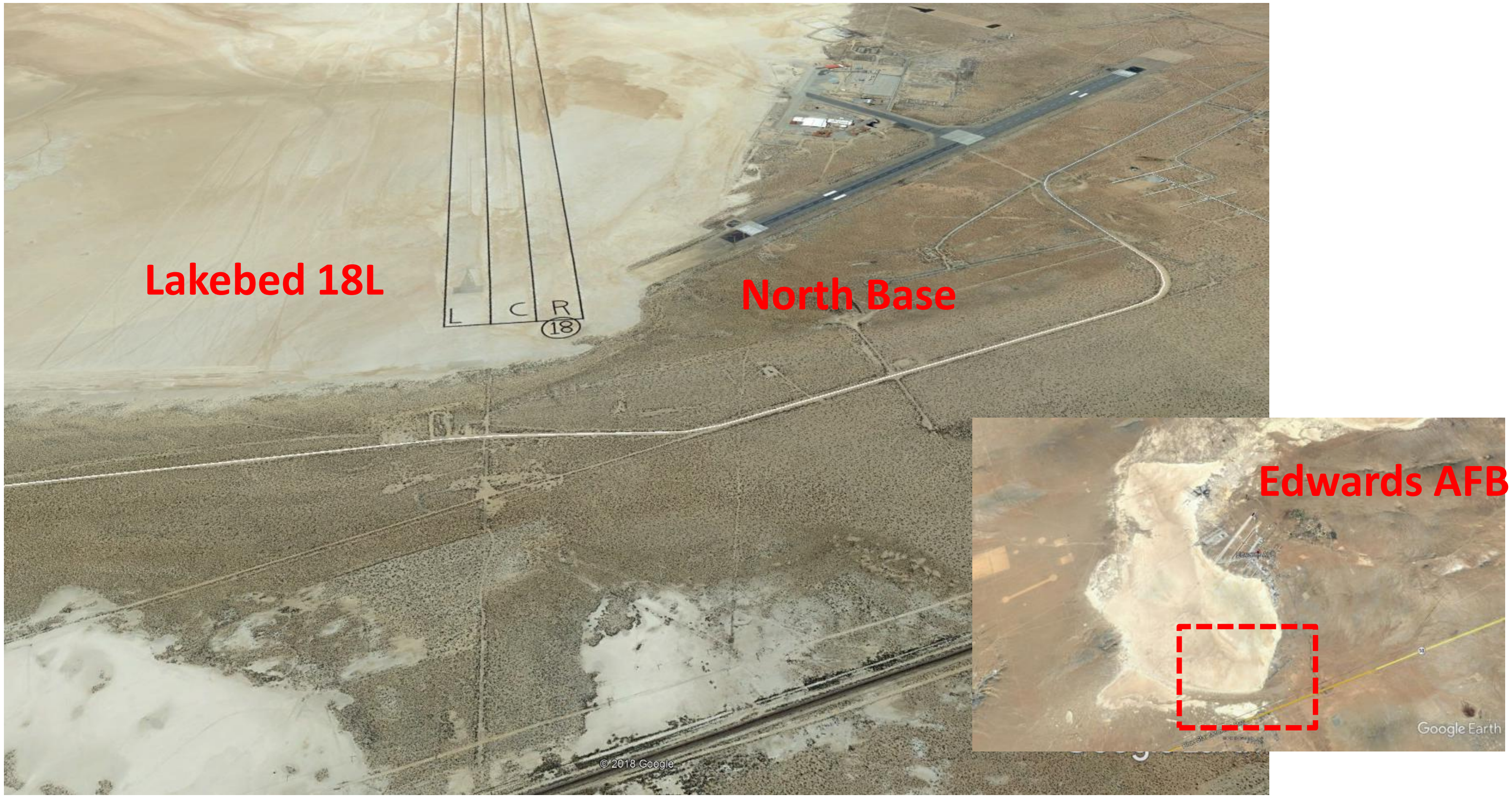
ARM Pilot Techniques

- **ARM research flights consisted of our Gulfstream's overflying NASA Langley Research Center's acoustic array, which was positioned on the approach end of lakebed runway 18L (and later North Base Runway)**

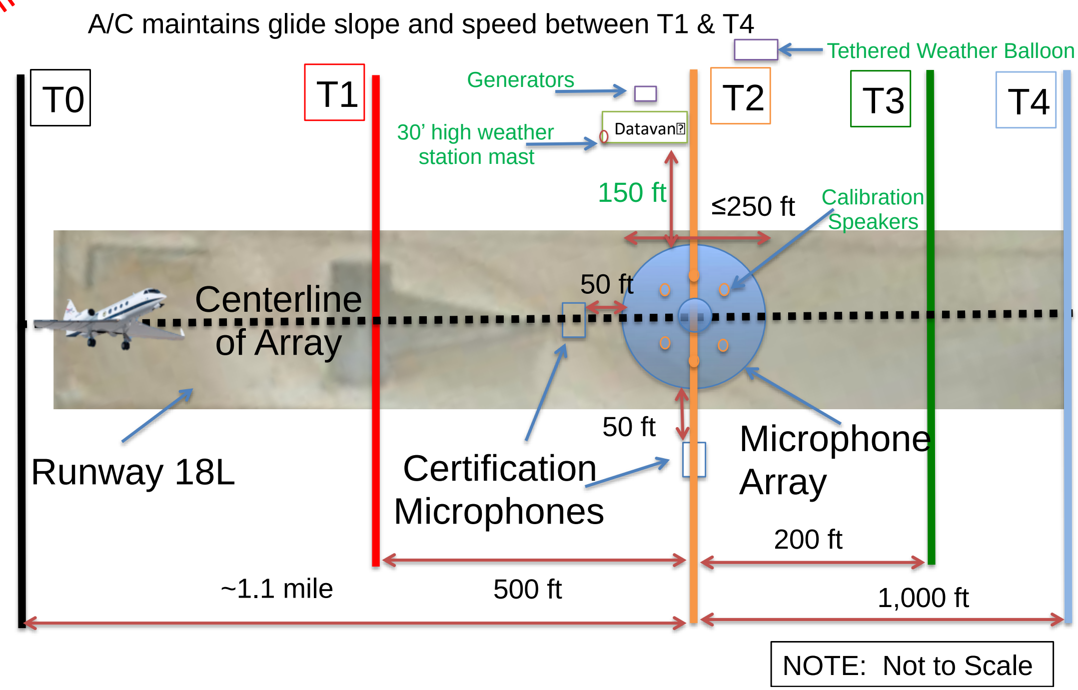


ARM Pilot Techniques

- **For acoustic data – the requirements were (from T0 to T4):**
  - At 350 +/-50', centerline +/-35'
  - Constant glide-path
  - Throttles- idle (engines as quiet as possible)
  - On speed
  - *A level platform*
  - *Consistency to build a statistical basis*

In order of priority

Requirements Determined later



- **The constraints were:**
  - Various configurations
    - Gear Up or Down:
    - Various Fowler or ACTE Flap settings
    - Various gross weights (due to fuel burn)
- **The consistency requirement led us to flying at least three runs in a row with the same configuration with 6 minutes between passes.**
- ***Not a simple 3 degree visual glide-path! (Throttle is at idle)***

Data from Simulator Trials

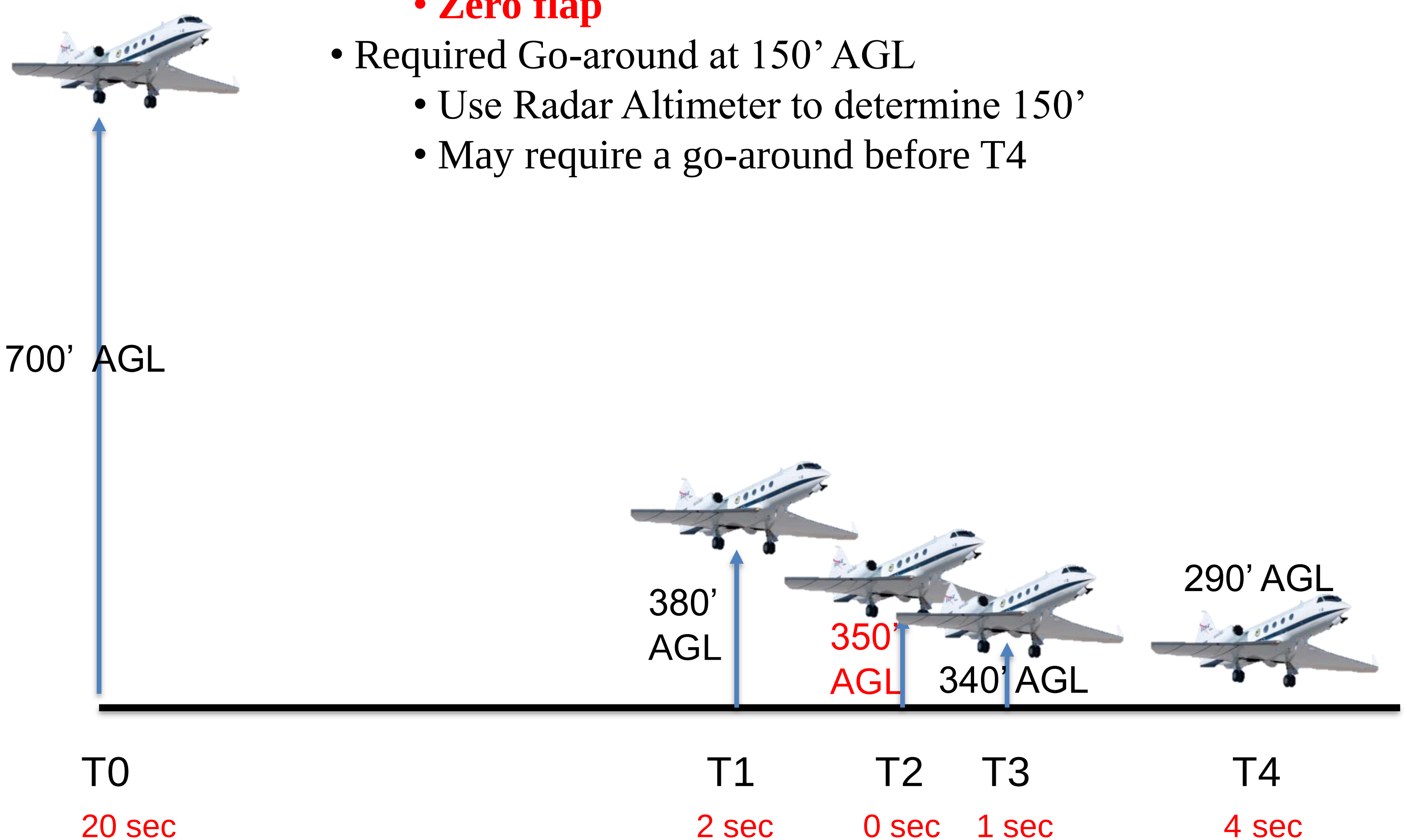
Configuration		Speed	Descent rate	Descent angle	
Gear	Flaps	(KCAS)	(fpm)	°	
Down	39	140	2100	8	"Front" side drag curve
Down	39	150	2400	9	
Down	39	165	3100	10.5	
UP	0	140	790	3	"Back" side drag curve
UP	0	150	800	2.6	
UP	0	165	810	2.5	
Down	0	150	870	3.1	

- Data collected at various altitudes from 3000' to 9500'
- 55,000 lb Gross Weight
- Standard Day conditions with both throttles in hard stop idle
- ***Minimum Go-around altitude is 150' AGL for Gear Dn/Flaps 39!***

"Descent on Final" Pass – Zero flap

- **Targeted altitude at center point of array is 350' AGL.**

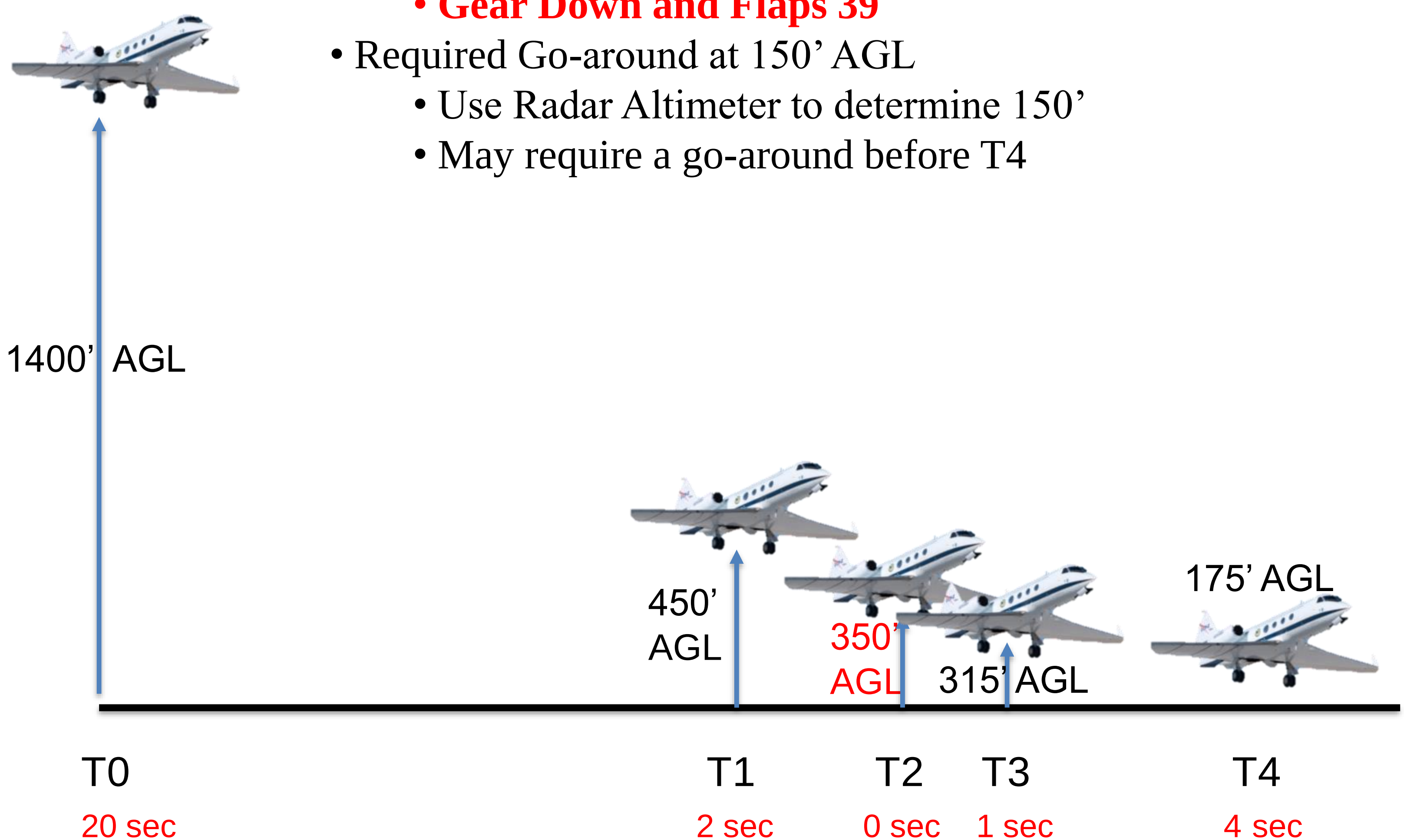
- **Shallowest Descent Shown**
  - **Zero flap**
- Required Go-around at 150' AGL
  - Use Radar Altimeter to determine 150'
  - May require a go-around before T4



ARM Approach Test Maneuver

- **Targeted altitude at center point of array is 350’ AGL.**

- **Steepest Descent Shown**
  - **Gear Down and Flaps 39**
- Required Go-around at 150’ AGL
  - Use Radar Altimeter to determine 150’
  - May require a go-around before T4



ARM Pilot Techniques

- **Risk Factor – Go-around**
  - Attempting to maintain a quiet descent until reaching T-4
  - Must account for single engine performance decrease
  - Must configurations are unchangeable
    - Gear down with fairings installed
      and/or
    - ACTE flaps
    - *Normal Gulfstream climb-out performance didn't apply*
  - *An inadvertent touchdown would have curtailed the project*

ARM Pilot Techniques

- **Other factors:**
  - Weather:
    - Wind shears at 500’ – 200’ AGL
      - Caused lateral deviations
      - Can add or subtract energy
  - Aircraft – the ACTE had the roll spoilers removed
    - Lateral control is degraded
  - Birds – ouch
  - Other noises
    - Trains
    - Other Edwards AFB jets in the vicinity
  - Human factors – very stringent and demanding
    - *Possibly more than a single pilot can handle*

ARM Pilot Techniques

- **So how do we do this?**
  - Specifically, control the altitude through the approach
    - Lateral deviation was accomplished visually
      - However, a visible centerline (i.e. runway centerline) is very helpful to minimize lateral deviations
  - *(What ever we do, we'll practice in the simulator first)*

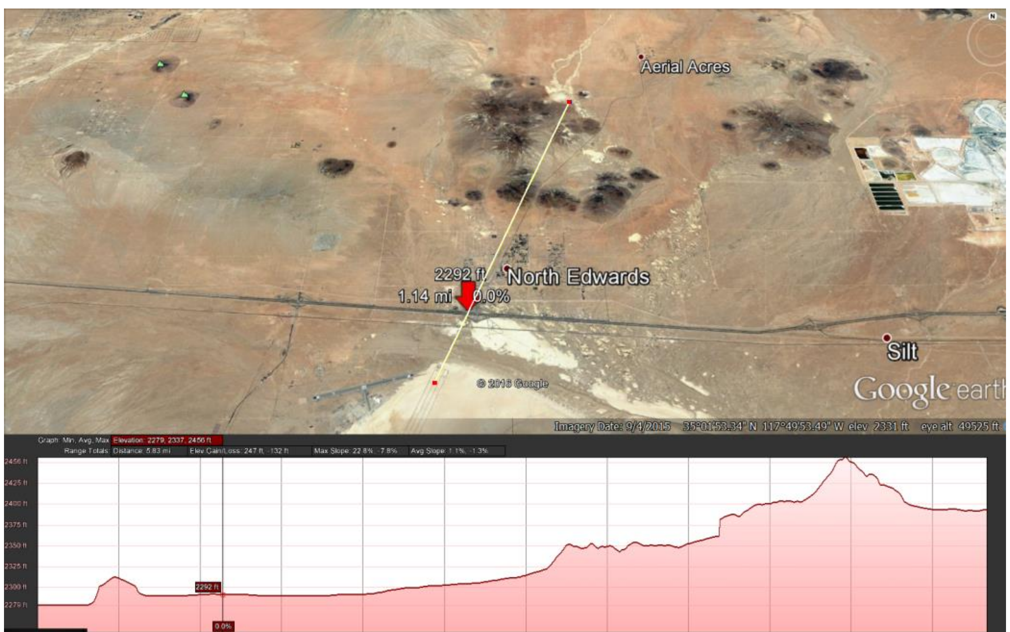
  - Tried several techniques
    1. A software based ILS with programmable glide-path presented on a tablet display
       - Too difficult or time consuming to program
    2. A tablet based altitude/lateral deviation prediction tool
    3. Visual Aim-Points
    4. FMS programmed user approach
    5. CRM (crew resource management)

ARM Pilot Techniques

- **A tablet based altitude/lateral deviation prediction tool**
  - Used RADAR altimeter data with differential GPS positioning
    - RADAR altimeter is the most accurate data available
      - It is also the recorded altitude data

12:32:15		ΔH (ft)
GRNDSPD (kts)	155.2	10 LO
ALT (AGL ft)	1300.1	
DIST TO T2 (mi)	3.50	
TIME TO T2 (min)	1.25	OFF (ft)
HDOT (K fpm)	1.20	25 RT
REQ HDOT (K fpm)	1.10	
FPATH (deg)	3.10	

Compare these on descent



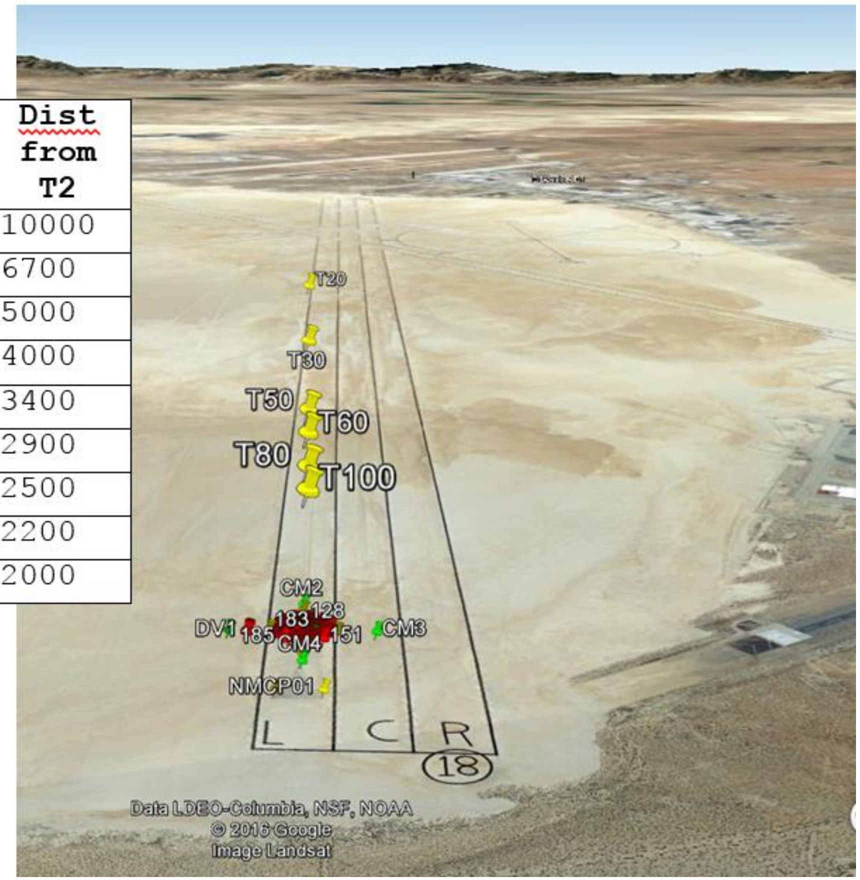
- Unfortunately, changing terrain on final will make RadAlt based solutions inaccurate
- The Req HDOT was a very valuable “trend” instrument

ARM Pilot Techniques

- **Visual Aim-points determined and displayed using Google Earth**
  - For a lakebed, it wasn’t that accurate due to lack of references
  - Did give the pilot a rough idea of where the aim-point needed to be

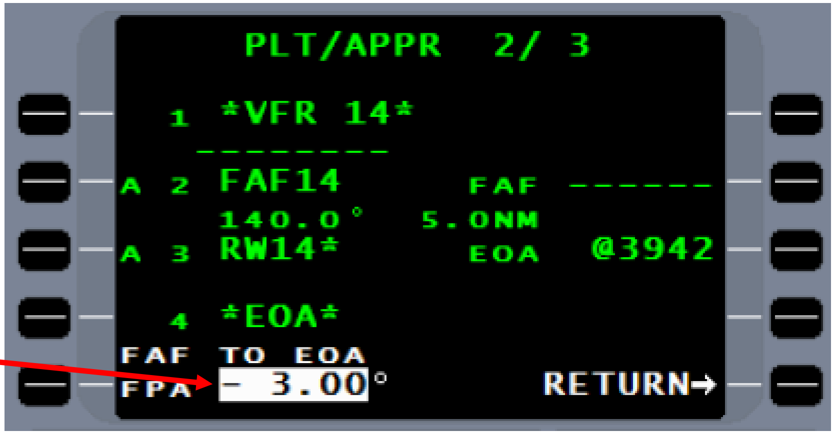
Visual Aimpoints (for ref 18L threshold to T2 is 1000’)

FPATH	Dist from T2
2.0	10000
3.0	6700
4.0	5000
5.0	4000
6.0	3400
7.0	2900
8.0	2500
9.0	2200
10.0	2000



ARM Pilot Techniques

- **FMS User Programmed approach**
  - Installed Universal Avionics provides the ability
    - For each approach, the Flight Path Angle (FPA) was adjusted



  - Fairly accurate but not sufficient to make corrections
    - Overall, this is still a visual approach so “flying the gauges” like an instrument approach did not develop the necessary consistency

ARM Pilot Techniques

- **Cockpit Resource Management**
  - Even though it is an visual approach, the Pilot Not Flying (PNF) can provide the necessary audible cues to the pilot
    - Some what like a Precision Approach RADAR (PAR)
    - Pilot Flying (PF) flies on course to a descent point at a Final Approach Fix (FAF) altitude that is 60 seconds to the array target “T2”
      - Timing based upon Tablet or iPad/Stratus/Foreflight
    - At 60 seconds to T2, the PF starts an idle descent
    - PNF calls predicted altitudes and deviations at 30 seconds and 15 seconds to “T2” based upon a look up table. PF makes appropriate adjustments
      - Spoilers (if available) or a momentary throttle burst (before T-0)
    - End-game – PNF calls out a countdown cadence “10, 9, 8, … mark” so the PF can adjust the pitch slightly to meet altitude tolerances

ARM Pilot Techniques

END GAME

- 15 sec call from the PNF i.e. “should be at 3050’, slightly high”
- Cadence call from PNF “10, 9, ..mark”
- PF watches the altimeter needle movement and adjusts pitch slightly so at “Mark” the needle goes through the target altitude
- PF also watches the RADAR altimeter readout to confirm 350’
- Further refinement – at the “6” second call the PF should be at an altitude equal to the target plus the 10% of the average fpm descent rate.
- Slight pitch adjustments did not affect the data

T-2 target altitude =~2270’ + 350’ = 2620’ MSL

Field Elevation=~2270’

So…. How do we build this visual approach?

- Again the descent occurs 60 sec from the target (about 3 nm) on final

1. **Identify the Target Altitude**
   - Fly a level pass marking the MSL altimeter reading that corresponds to 350' AGL on the RADAR Altimeter
2. **Identify the "Final Approach Fix" FAF altitude**
   - At ~4000' AGL, configure the aircraft for the desired test point
   - Establish a stabilized idle descent at the target airspeed
   - Determine the altitude loss in 60 sec
   - PF determines a pitch attitude to start the descent
   - Add the altitude loss to the target altitude = FAF altitude
3. **Identify a go-around altitude**
   - At the end of the descent, determine altitude loss during a Go-around
   - Add 100' to the altitude loss = Go-around altitude
   - Rapid descents and conversely high Angle of Attack descents typically require more altitude to go around

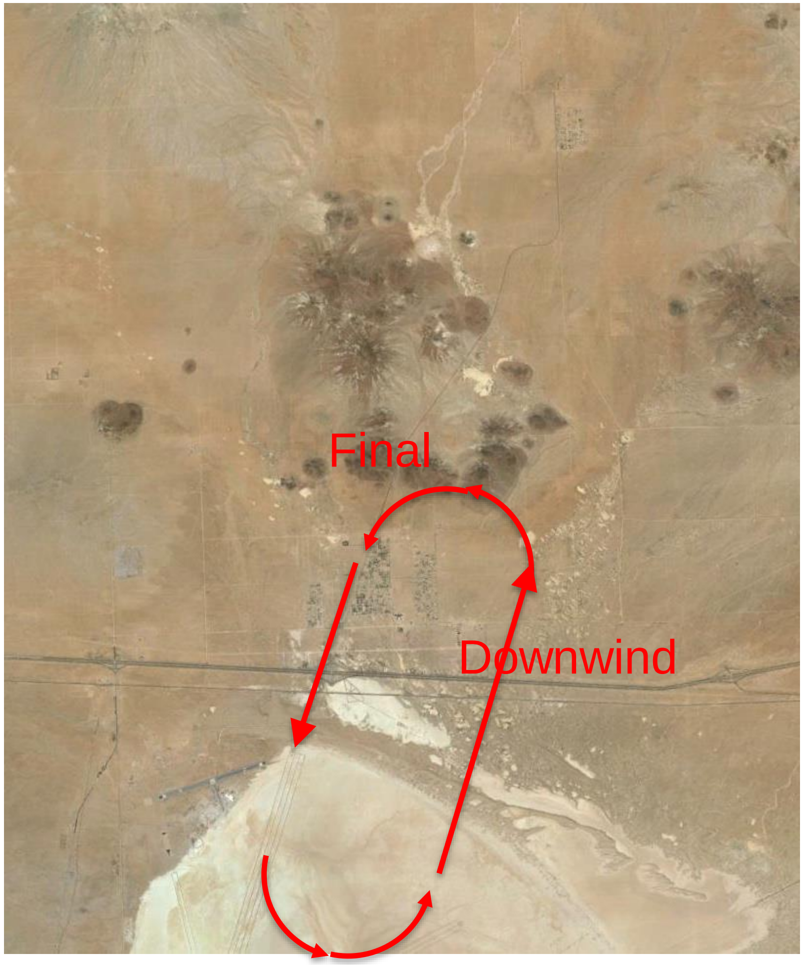
ARM Pilot Techniques

- **Look Up Table**
  - FAF (60 sec), 30 sec, and 15 second altitudes
  - After determining the altitude loss in 60 sec
  - For instance, 2100' altitude loss corresponds to 4720, 3670, and 3150 for the FAF, 30, 15 sec predicted altitudes

FAF and Target altitudes (MSL)

VSI	"FAF" 60 sec	30 sec	15 sec	VSI	"FAF" 60 sec	30 sec	15 sec
600	3220	2920	2770	2000	4620	3620	3120
650	3270	2950	2780	2050	4670	3650	3130
700	3320	2970	2800	2100	4720	3670	3150
750	3370	3000	2810	2150	4770	3700	3160
800	3420	3020	2820	2200	4820	3720	3170
850	3470	3050	2830	2250	4870	3750	3180
900	3520	3070	2850	2300	4920	3770	3200
950	3570	3100	2860	2350	4970	3800	3210
1000	3620	3120	2870	2400	5020	3820	3220
1050	3670	3150	2880	2450	5070	3850	3230
1100	3720	3170	2900	2500	5120	3870	3250
1150	3770	3200	2910	2550	5170	3900	3260
1200	3820	3220	2920	2600	5220	3920	3270
1250	3870	3250	2930	2650	5270	3950	3280
1300	3920	3270	2950	2700	5320	3970	3300
1350	3970	3300	2960	2750	5370	4000	3310
1400	4020	3320	2970	2800	5420	4020	3320
1450	4070	3350	2980	2850	5470	4050	3330
1500	4120	3370	3000	2900	5520	4070	3350
1550	4170	3400	3010	2950	5570	4100	3360
1600	4220	3420	3020	3000	5620	4120	3370
1650	4270	3450	3030	3050	5670	4150	3380
1700	4320	3470	3050	3100	5720	4170	3400
1750	4370	3500	3060	3150	5770	4200	3410
1800	4420	3520	3070	3200	5820	4220	3420
1850	4470	3550	3080	3250	5870	4250	3430
1900	4520	3570	3100	3300	5920	4270	3450
1950	4570	3600	3110	3350	5970	4300	3460

Level Pass

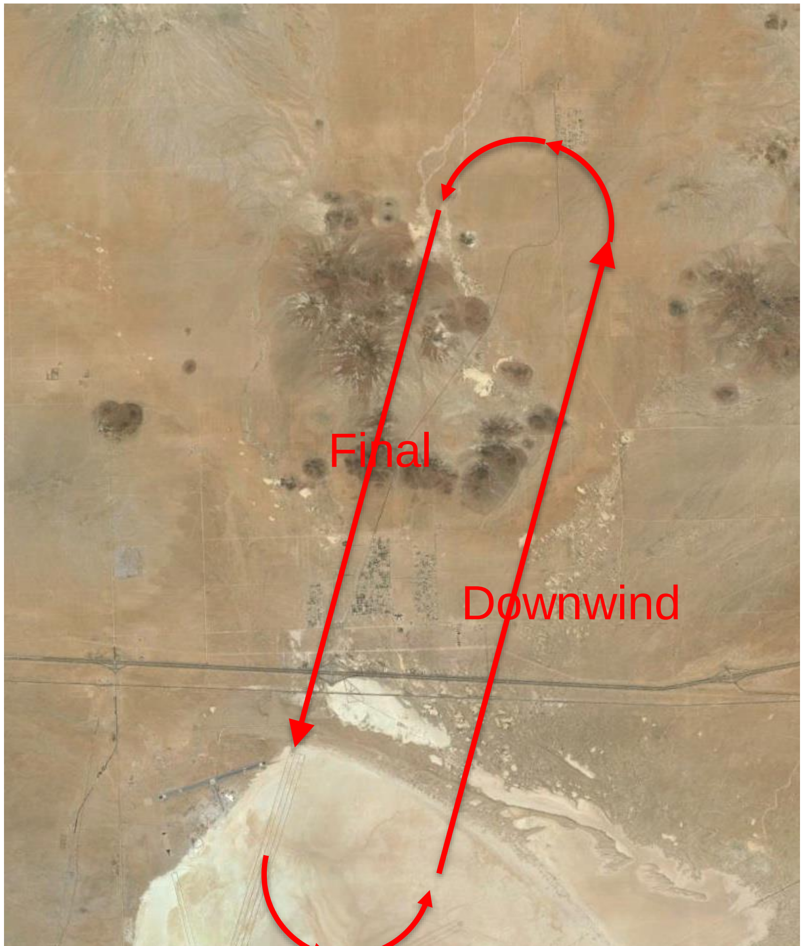


Objectives - Cross T2 (in priority)

- At 350 +/-50', centerline +/-35'
  - ~ 2650' MSL
- Level
- Throttles - as required but stable
- On speed
- "Bug" the altimeter

ARM Pilot Techniques

"Descent on Final" Pass



Similar to a precision approach but with a non-standard glide path

- Downwind -Descent glide path determined
  - Fly idle decent on target speed to determine descent glide path
  - Practice go-around at altitude
  - Climb to a final approach "start descent" altitude based on descent profile
  - Downwind descent not required if descent profile (airspeed, configuration) previously determined
- **Base turn >= 5 nm**
- **Final**
  - Start idle decent on target speed at 60 sec to T2
  - Time to T2 ETE determined using tablet, iPad, and/or FMS
- **Early go-around if T2 parameters cannot be met**
- At 350 +/-50', centerline +/-35'
- Constant glide-path
- Throttles- idle
- On speed

ARM Pilot Techniques

- **Multiple passes with the same configuration and speed**
  - Allowed us to fine tune the altitudes for the next pass
    - i.e. if we were 50’ high on the first pass then we would subtract 50’ from the FAF altitudes on the next pass
- **Unique challenges**
  - Shifting crosswinds over the array
    - To maintain wings level we often set up left or right then drifted across close to centerline
  - Altitude wind gradients (different winds at different altitudes)
    - Tend to add or subtract energy – 5 kts = ~50’ to compensate
    - The 60 sec ETE method theoretically only works for constant winds.

ARM Pilot Techniques

Success – 1058 total passes over the array

- All *safely* accomplished
- Approximately 87% passes were within parameters

Collaboration is the key

- Four different test pilots each contributed to improvements in procedures and techniques
- Principal investigator who emphasized the important elements to his data in debriefs
- Field crew lead who is familiar with what is happening in the cockpit and attends pre- and post-flight briefs is essential

Applications to other aircraft and other locations

- Absolutely – a safe build-up is necessary
  - A simulator is essential

ARM Pilot Techniques

- **Backup**

Go-Around

- **A Go-around is practiced on downwind at a higher altitude**
  - Determine a min go-around altitude
    - See how much altitude is lost – use aircraft altimeters
      - Add 100’ to this number for a min go-around altitude
  - See if stick shaker is an issue
  - Use 10 deg nose up and full throttles
- **Go-around on final**
  - Called by **PM** at (whichever occurs first)
    - Reaching T4,
    - Min go-around altitude (determined above) (use RadAlt)
    - ***150’ (use RadAlt)***

CRM on final approach

- **PF**
  - Remember the ADI descent angle during the stabilized idle descent so you can quickly set that pitch at the start descent point.
  - Attain and maintain centerline visually
  - Make pitch adjustments based upon PM glideslope calls
  - If slow, increase throttles momentarily – be sure to be idle at 10 sec to T2
  - If fast then use spoilers momentarily (Fowler) or accept a speed increase (ACTE)
  - Remember KIAS crossing T2
- **PM**
  - Take notes on the test cards to support corrections for the next pass
  - Call start descent based on methods previous slide
  - Make “PAR” like glideslope calls based on tablet Hdot, Reqd Hdot
    - When Hdot = Reqd Hdot - you should be on the correct glideslope to cross T2 at 350’
      - Call push or pull if necessary to get in the 350+/-50’ window
  - Make periodic time to T2 calls
  - Radio out “turning in”, “T0”
  - Call Go-around

“Descent on Final” Pass – Zero flap

- Gear will be down for practice flights
- Zero flap – Descent Shown (based on sim)
  - Gear Down and Flaps zero
- Required Go-around at 150’ AGL
  - Use Radar Altimeter to determine 150’
- End game solution
  - Start approach >1 min out – to stabilize
  - Adjust power as necessary to adjust energy
  - Use tablet or iPad “Required descent” versus “Current descent” for glide-path corrections (and CRM)
  - Ideally we would have a standard precision approach display with an adjustable glide-path angle
    - Based on current sim results

700’ AGL

380’ AGL

350’ AGL

340’ AGL

290’ AGL

T0	T1	T2	T3	T4
20 sec	2 sec	0 sec	1 sec	4 sec

ARM Displays: Objectives

Pilot Display: Help pilots guide aircraft over microphone array

- Fly over microphone array at idle power to measure acoustic signature
- Target altitude 350 ft (AGL) +/- 50 ft
- Maximum lateral offset +/- 35 ft from centerline
- Multiple aircraft configurations, flight conditions → 800 - 2400 fpm descent rate

FTE Display: Provide position triggered aircraft state information to Flight Test Engineer

- As aircraft flies over predefined points, display aircraft state information to FTE
- Provides researchers with "quick look" data to determine if pass meets research requirements

	TIME	GRNDSPD (KTS)	HT (AGL FT)	LAT OFF (FT)
T0	12:30:15	152.5	2580.6	30.99 LT
T1	0.0	0.0	0.0	0.0
T2	0.0	0.0	0.0	0.0
T3	0.0	0.0	0.0	0.0

12:32:15

Racetrack Pattern

Basic pattern

- Descent pass –
  - 6000’ MSL Downwind
  - ~5 mile final
  - ~6-8 min per pass
- Level pass
  - 4000’ MSL Downwind
  - ~2 mile final
  - ~4 min per pass
- Tower Flyby and North Re-entry pattern could be a conflict
  - In contact with EDW tower for deconfliction