Foundational Terminal Operations HITL

Experimental Design Slides

11 JULY 2017

Ongoing Development Efforts

- Vigilant Spirit
  - Displaying vertical speed bands
  - Displaying new well clear recovery format (heading, altitude & vertical speed)
  - Multi ownship control (background ownships may be powered off or in a tight loiter pattern)
- CADASEUS
  - JADEM-DAIDALUS integration – on schedule, in verification stage
  - Well clear recovery in horizontal & vertical dimensions simultaneously (also provided for vertical speed and speed)
  - Vertical speed DAA bands
  - Multi ownship – looks like minimal effort/impact to change ‘set ownship’ message; performing experiment to verify expected changes work as expected
  - DAIDALUS multiple alert & guidance configurations (with/out corrective alert level and/or corrective or preventive guidance)
- LVC
  - Gateway changes to allow for omni bands and well clear recovery (done by end of week)
  - SSA – has to be modified to allow for multi ownships
- Logistics
  - ISA COMPLETED
  - Start-up procedures
  - Participant recruitment

Foundational Terminal Ops HITL

- Purpose: Examine issues related to the operation of the Phase 1 DAA system within a Class D Terminal Area. The following operations will be examined:
  - Instrument approach
  - Visual approach
  - Visual pattern
- Objectives:
  - Characterize pilot behavior in terminal environment w/ Phase 1 DWC definition
  - Investigate effect of modifications to the Phase 1 DAA alerting and guidance
  - Develop simulation architecture and scenarios representative of a Class D terminal environment

Experimental Design

- Independent Variable: DAA Alert Structure Configurations (between subjects)
  1. Full Phase 1 MOPS DAA alerting and guidance (Class I)
  2. No corrective alert: preventive → warning
     - *With corrective suggestive guidance*
  3. No corrective alert: preventive → warning
     - *With preventive suggestive guidance*
  4. No corrective alert: preventive → warning
     - *Without corrective or preventive suggestive guidance*

Phase 1 Alerting

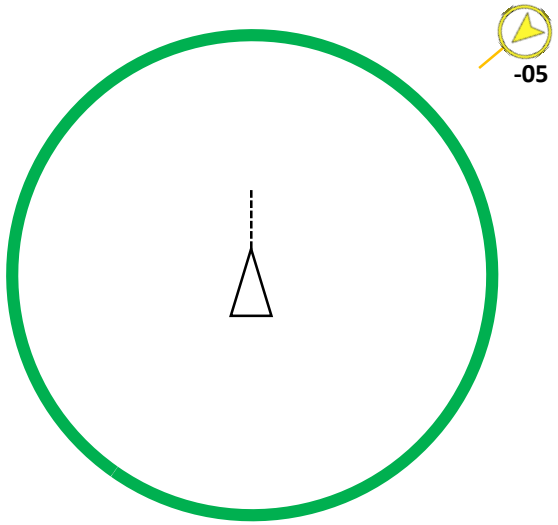
Symbol	Name
	Warning Alert
	Corrective Alert
	Preventive Alert
	Guidance Traffic
	Remaining Traffic

No CORR Alert

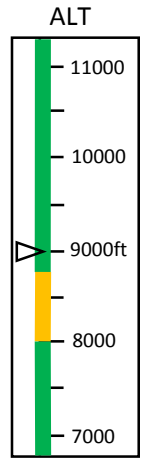
Symbol	Name
	Warning Alert
	Preventive Alert
	Guidance Traffic
	Remaining Traffic

1. Full Phase 1 MOPS DAA alerting and guidance (Class I)

Truth = PREV threat, no LoDWC



Inner Range Ring



Altitude Tape

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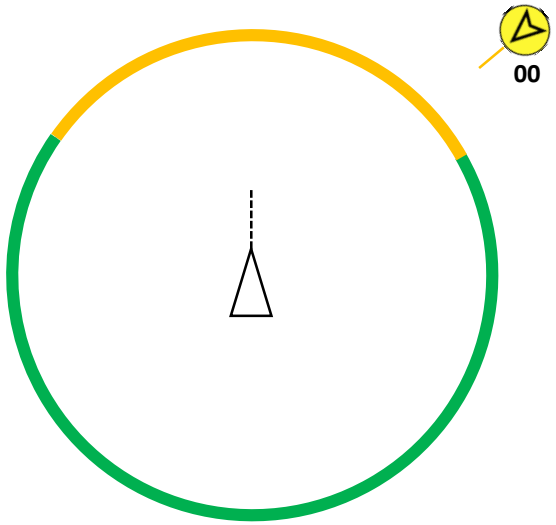

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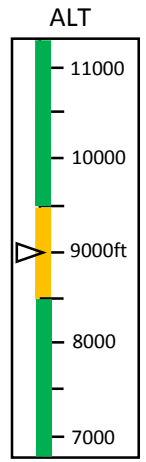

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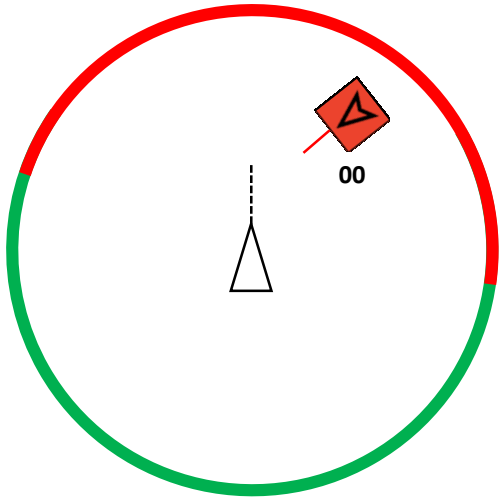

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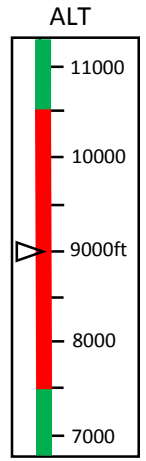

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2. No corrective alert: preventive → warning
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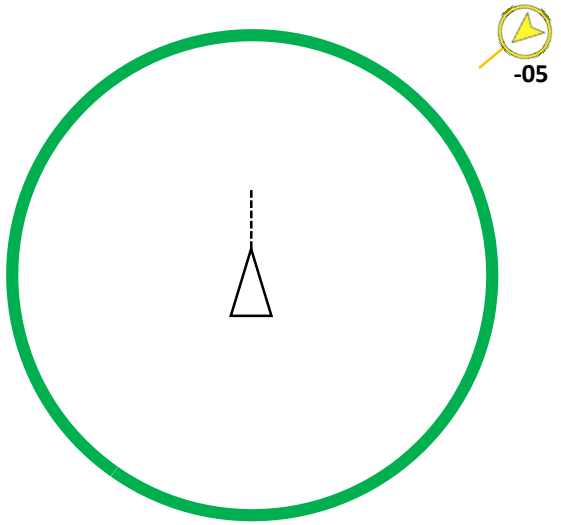

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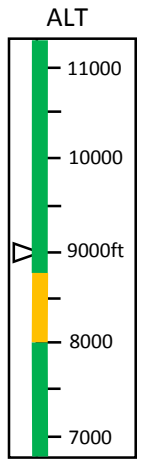

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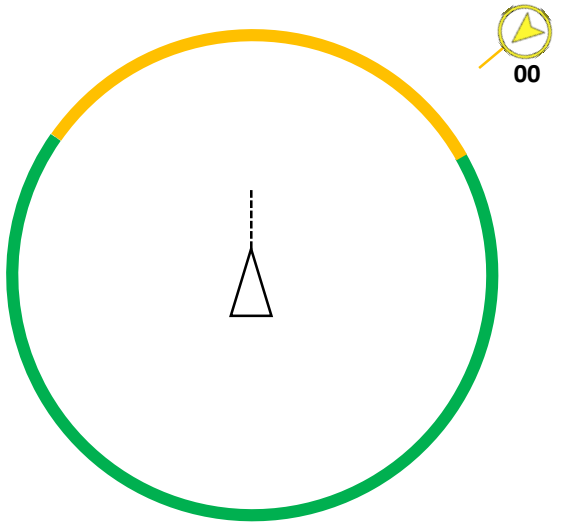

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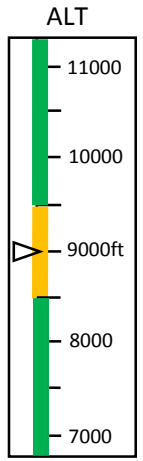

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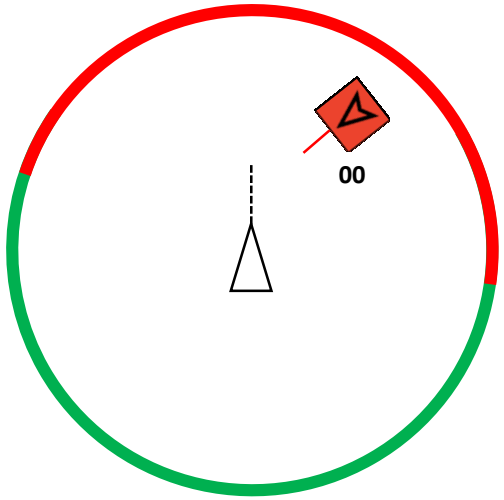

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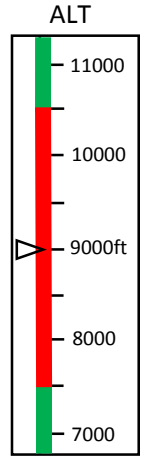

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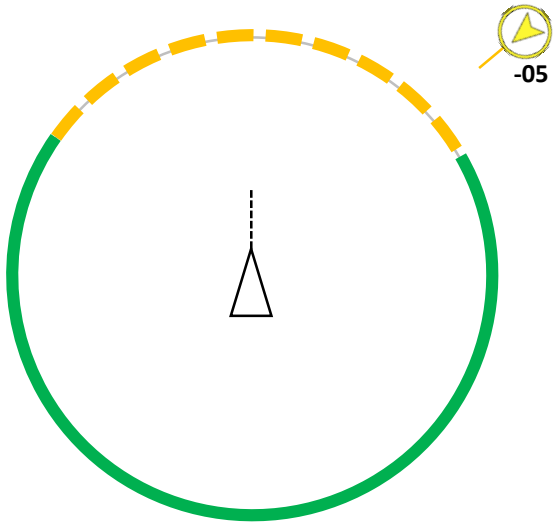

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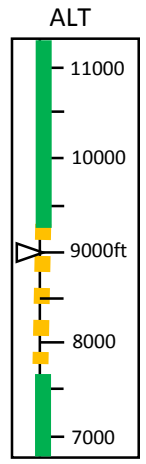

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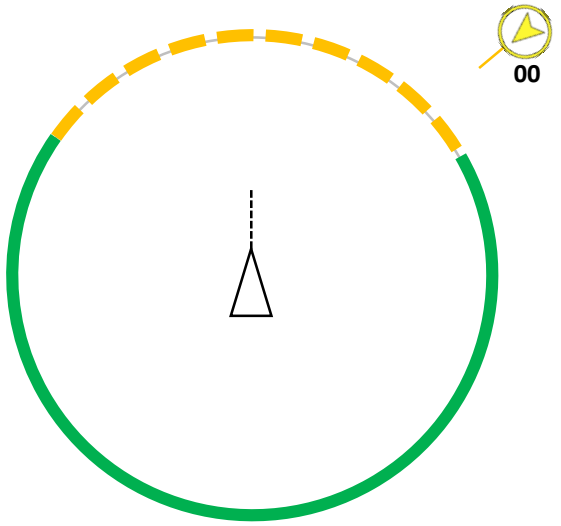

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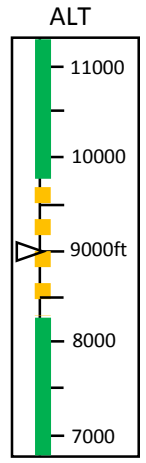

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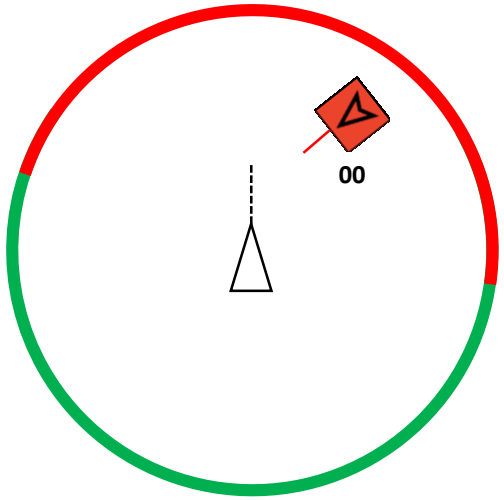

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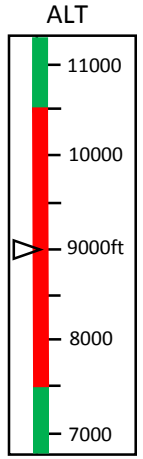

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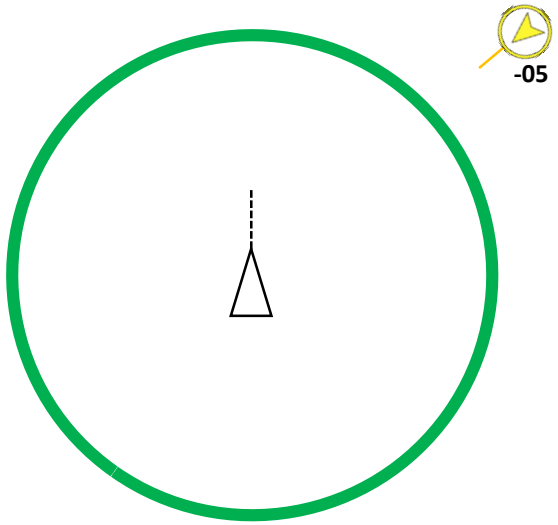

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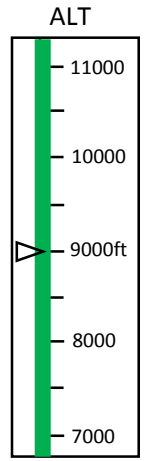

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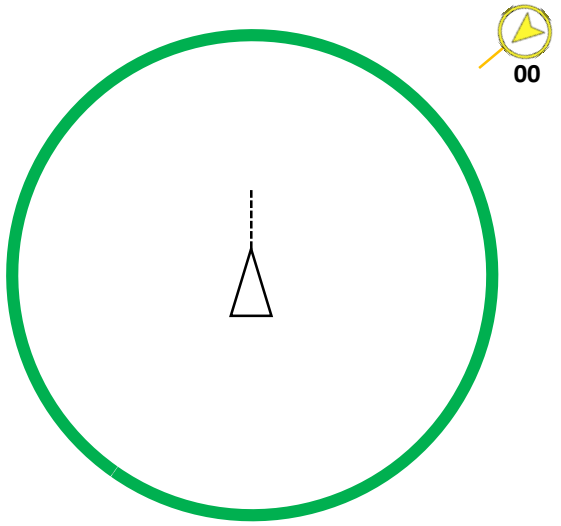

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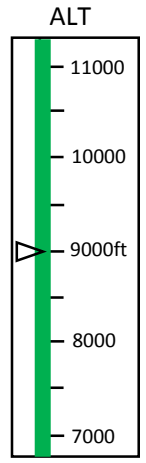

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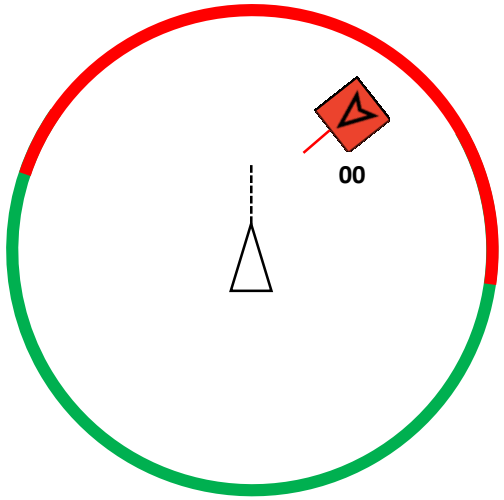

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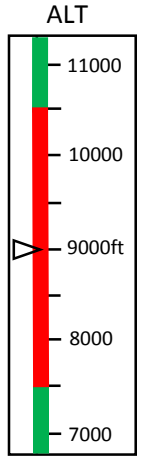


Altitude Tape

Note: ~15s to LoDWC

Experimental Design

- Independent Variable (within subjects)
  1. Baseline with no alerting – prior to learning DAA alert level
- Embedded Variables:
  - Encounter Type
    - Threat at first alert
      - Corrective (post processing can ID threats that would have started as CORR in conditions without CORR alert)
      - Warning
    - Severity
      - NMAC predicted
      - No NMAC predicted (can be subdivided by level of severity, e.g., 10-75% penetration predicted)
    - Geometry
      - Head-on, crossing, overtaking
    - Intruder Phase of Approach
      - Overflight, turning into final in front of ownship, in traffic pattern, departure

Baseline

Symbol	Name
	Remaining Traffic

Experimental Design

- Dependent Variables:
  - Performance Metrics
    - Separation Data
      - Proportion & severity of LoDWC
      - Minimum HMD per LoDWC
      - Proportion of NMACS
    - Measured Response
      - Initial RT, Edit Times, Aircraft/Total RT
      - ATC comm times
    - Alert Characteristics
      - Ownship location (lat/long, alt, etc) & phase of approach (straight-instrument, downwind, etc) when alert is issued
      - Ownship time and distance to touchdown point when alert is issued
        - Need to ID single touchdown point
      - Ownship position relative to precision approach intersection w/ runway
      - Intruder location (absolute & relative to ownship) and phase of approach when alert is issued

Experimental Design

- Dependent Variables:
  - Performance Metrics
    - Maneuver Data
      - Ownship position and phase of approach when evasive maneuver initiated
      - Type of evasive maneuver
        - Turn, change of vertical rate, no maneuver
    - ATC Acceptability/Interoperability
      - Ownship position and phase of approach when contacting ATC
      - Number of calls to ATC
      - Misunderstanding or mis-execution of ATC clearances
      - Notable/odd behavior from UAS pilot
      - Number of early-late calls to ATC
      - Number of close-far maneuvers

Experimental Design

- Dependent Variables:
  - Performance Metrics
    - Operational Performance
      - Number of maneuvers w/out ATC clearance or DAA alert
      - Distance from lead aircraft (visual approach)
      - Ability to enter traffic pattern (traffic pattern)
        - Angle of entry, spacing w/ lead aircraft, # of attempts
      - Number of missed approaches/go-arounds
  - Subjective Metrics
    - Factors contributing to when/how to maneuver:
      - Right of way
      - If no maneuver made:
        - Intruder motion was predictable
        - Situation considered safe to continue approach
        - Abandoning approach unnecessary

Operational Assumptions

- UAS Capabilities
  - Class 1 DAA system – no collision avoidance alerting or guidance (i.e., TCAS II)
  - UAS has means for acquiring runway/confirming runway clear
  - UAS not picking up ground tracks (presume a filter will be applied to prevent them from appearing on traffic display)
- ATC coordination
  - In instrument & visual approach scenarios, tower is treating UAS like any other IFR aircraft
  - In traffic pattern scenario, tower is treating UAS like any other VFR aircraft
  - ATC not making traffic calls to UAS
- Manned traffic not making maneuvers against UAS
  - Manned traffic will confirm “traffic in sight” against the UAS when appropriate (e.g., when it coordinated its turn in front of UAS with tower)
- Weather/environment
  - VFR conditions
  - Wake turbulence not a consideration in scenario development

Scenarios

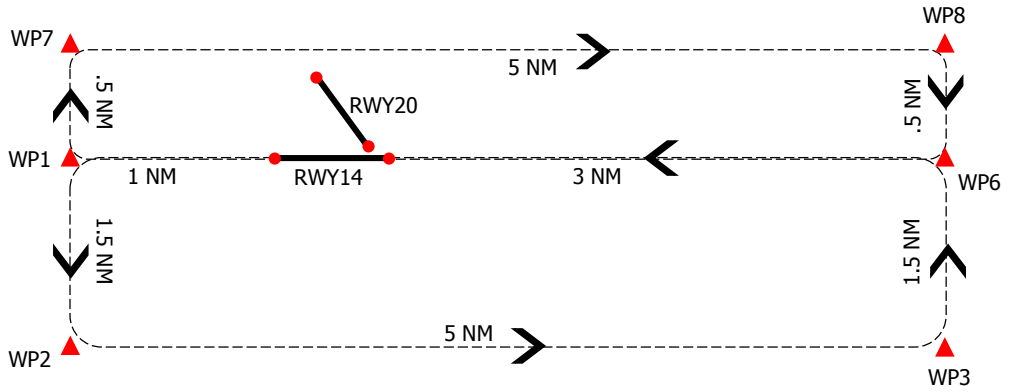
- Goal: pilots fly three different categories of approaches and are responsible for maintaining safety of aircraft
  - Pilot trained to ultimately use *own discretion*; however they will be trained on the meaning of each alert level included in their configuration
  - Some approaches will result in a conflict w/ an intruder that is predicted to result in an NMAC, while other intruders will only set off alerts
    - Possible to get alerts w/out an actual LoDWC
    - Any LoDWC that do occur will typically be low in severity
  - Note: entire approach does not need to be flown if pilot determines an evasive maneuver is necessary

Ownship Scenario	Description	Scenario Variations	ATC Comms	VSCS Interaction	Encounter Types	Metrics	Knock-it-Off
Instrument Approach (IFR)	• RNAV (GPS) Rwy 14 approach • Non-precision approach; flown via GPS avionics	1. Start point NW of CABEX 2. Start point NE of FIPUM	1. ZOA40 vectors ownship to LOZWU (IAF) @5000 2. @ LOZWU, ZOA40 clears ownship for approach & terminates radar services, sends to Tower 3. Contact Tower, ownship provides location and desired landing 4. Tower clears to land ~5nm (UCEVE) out from Rwy14	1. HOLDS on way to LOZWU @5000 2. @ LOZWU enter NAV mode (route has standard descent programmed to reach EHETY @3300) 3. @ EHETY enter glide slope (flown through landing) 4. Missed approach = runway heading (direct WDSTC), climb to 5000ft	1. Overflight b/w LOZWU & EHETY • NMAC & low-severity LoDWC 2. Blunder/vector in front of ownship on final • NMAC & low-severity LoDWC 3. No scripted conflicts (x2) • Traffic in pattern may cause alerts	• Ownship location/ phase of approach when missed approach engaged	• Engages missed approach (and pilot acknowledges they're done)
Visual Approach (IFR)	• Approach conducted under IFR but through ATC-approved visual clearance • Pilot must have either airport or a lead aircraft in sight	1. Start point NW of WP6 2. Start point NE of WP6	1. ZOA40 vectors ownship direct to STS, terminates radar services, and sends to Tower 2. Ownship contacts Tower and provides location and requests visual approach 3. Tower: "report airport in sight," or advises HAWK of traffic: "follow NXX, cleared for the visual approach" 4. Tower advises ownship to follow lead aircraft, eventually cleared to land	1. HOLDS on way to WP6/trailing lead aircraft 2. @ WP6 enter NAV with glide slope (flown through runway) 3. Missed approach = runway heading (direct WDSTC), climb to 5000ft	1. Overflight b/w starting point & WP6 • NMAC & low-severity LoDWC 2. Blunder/vector in front of ownship on final • NMAC & low-severity LoDWC 3. No scripted conflicts (x2) • Traffic in pattern may cause alerts	• Distance maintained in trail	• Run through minimum decision height
Traffic Pattern (VFR)	• Used to sequence (typically VFR) arrivals and departures • Prop pattern=1150ft • Jet pattern=1500ft • IFR pattern=5000ft (under Oakland center control)	1. Start point E of WP2 (for 45° entry into the downwind) 2. Start point W of ACUTI & 500ft above pattern altitude (for mid-field entry)	1. HAWK checks in with Tower and provides location and desired landing (e.g., requesting entry into the down wind Rwy14) 2. Tower asks HAWK to report 2-4nm out, after which HAWK will be cleared into the down wind (or clear to land if nobody on runway)	1. HOLDS to enter and turn in pattern 2. @ WP6 enter NAV with glide slope (flown through runway) 3. No missed approaches – exit and re-enter pattern	1. Overflight b/w initial point & entry point • NMAC & low-severity LoDWC 2. Departing aircraft conflicts while ownship on final • NMAC & low-severity LoDWC 3. No scripted conflicts (x2) • Traffic in pattern may cause alerts	• Ability to enter pattern (spacing from other aircraft, angle of entry)	• Run through minimum decision height

KSTS Rwy14 Left & Right-hand Traffic Patterns

PATTERN ALTITUDES

Jets	1500’ MSL
Props	1150’ MSL
Overhead	2000’ MSL



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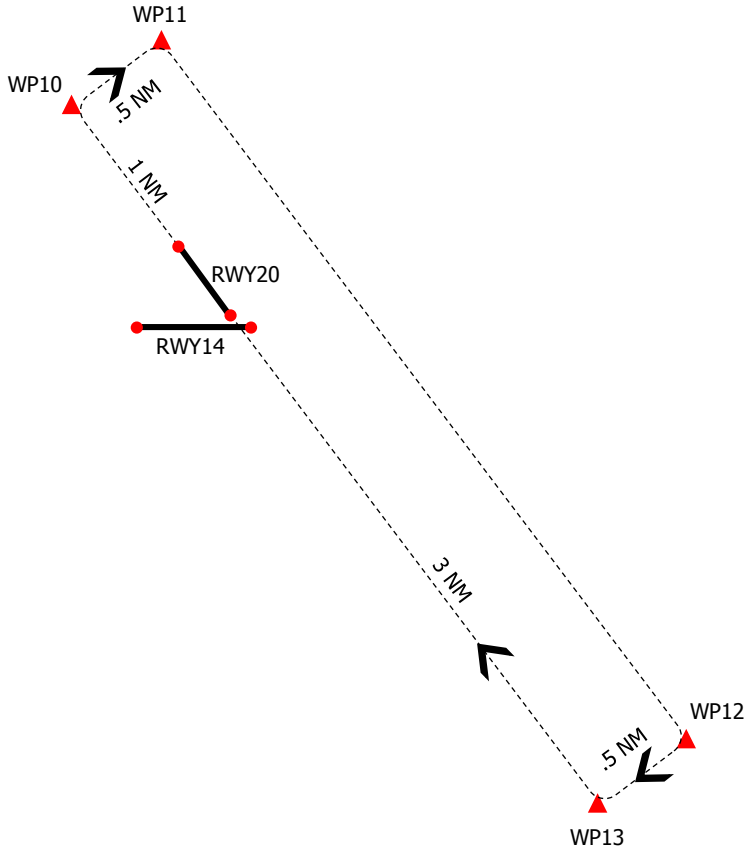

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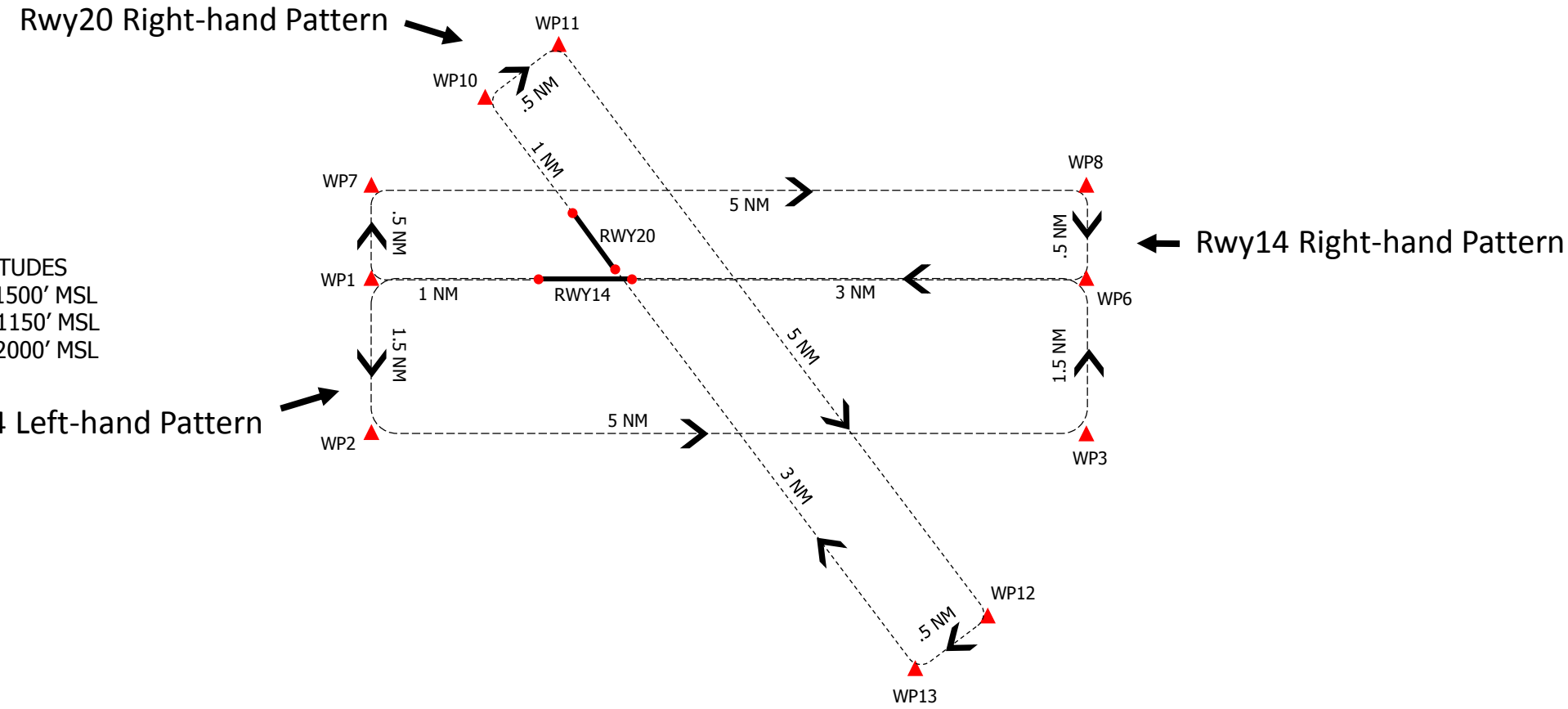
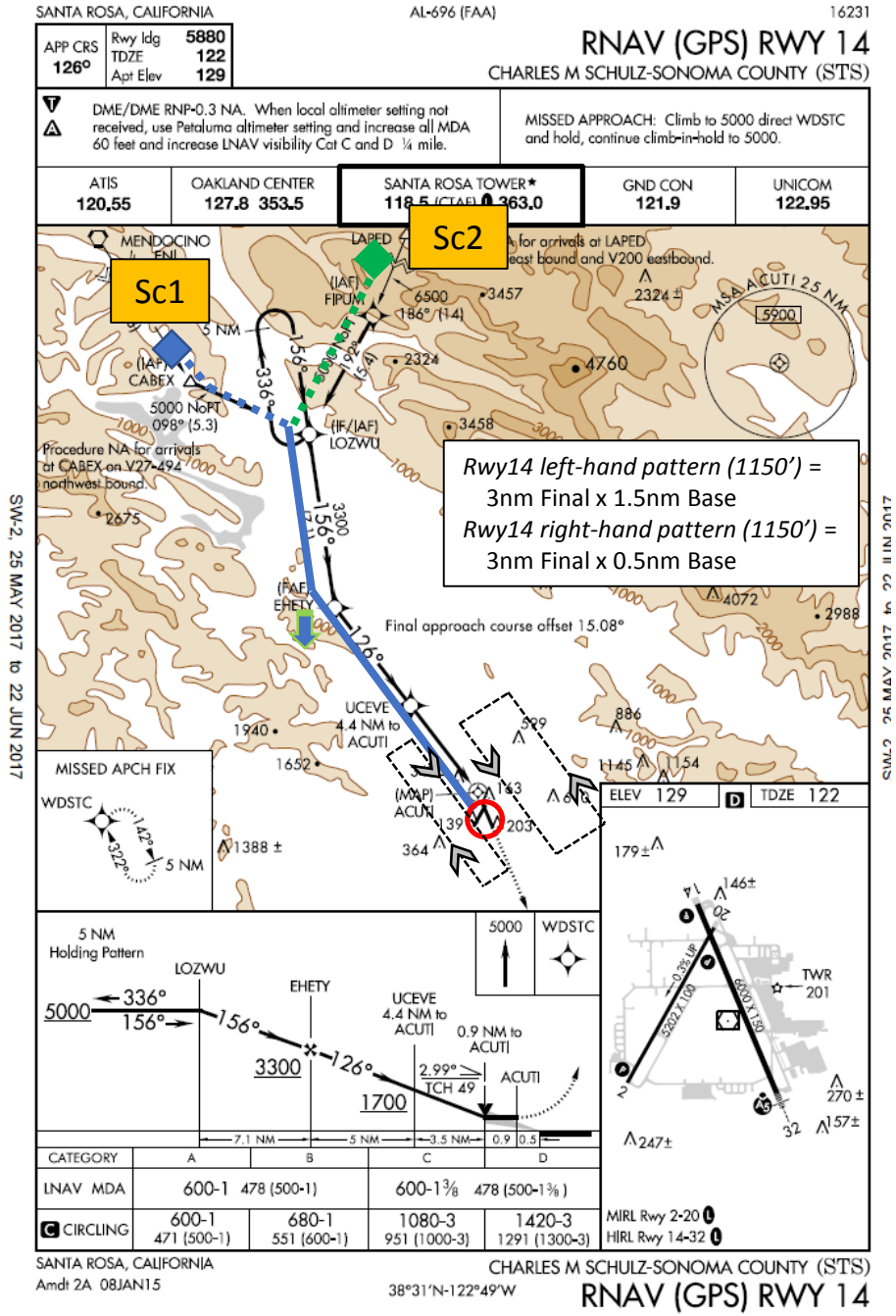


PATTERN ALTITUDES

Jets	1500′ MSL
Props	1150′ MSL
Overhead	2000′ MSL

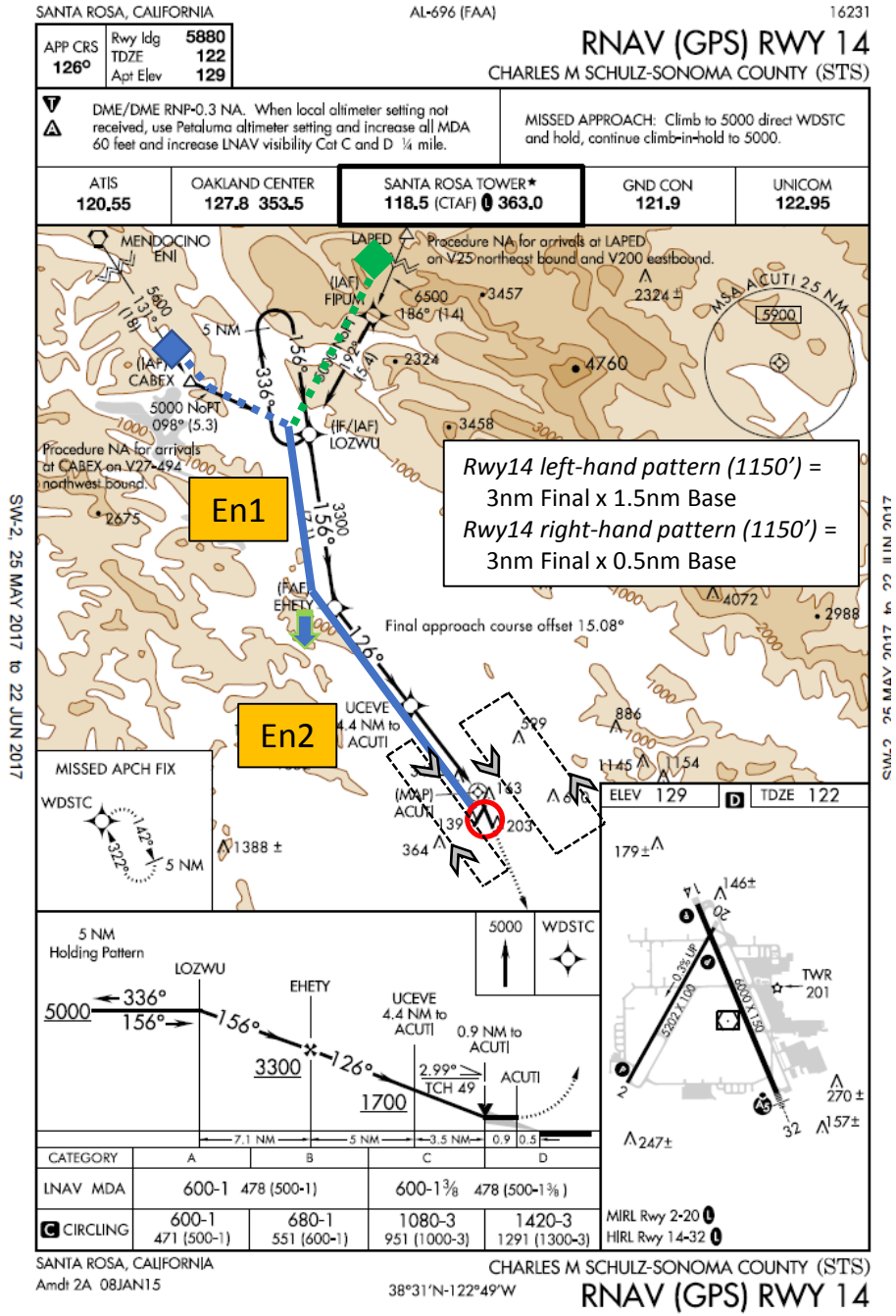
Instrument Approach Ownship Scenarios

- Ownship starting point:
  - Sc1: NW of CABEX
  - Sc2: NE of FIPUM
- Initial navigation mode: HOLDS mode
- Initial control sector: ZOA40
- ATC coordination:
  1. ZOA40 vectors ownship to LOZWU (IAF) @5000
  2. @ LOZWU, ZOA40 clears ownship for approach & terminates radar services, sends to Tower
  3. Contact Tower, ownship provides location and desired landing
  4. Tower clears to land ~5nm (UCEVE) out from Rwy14
- VS interaction:
  1. Use HOLDS mode to reach LOZWU @5000
  2. @ LOZWU enter NAV mode; route has standard descent programmed to reach EHETY (FAF) @3300
  3. @ EHETY route has glide slope programmed through UCEVE, ACUTI and Rwy14
  4. Missed approach = runway heading (direct WDSTC), climb to 5000ft



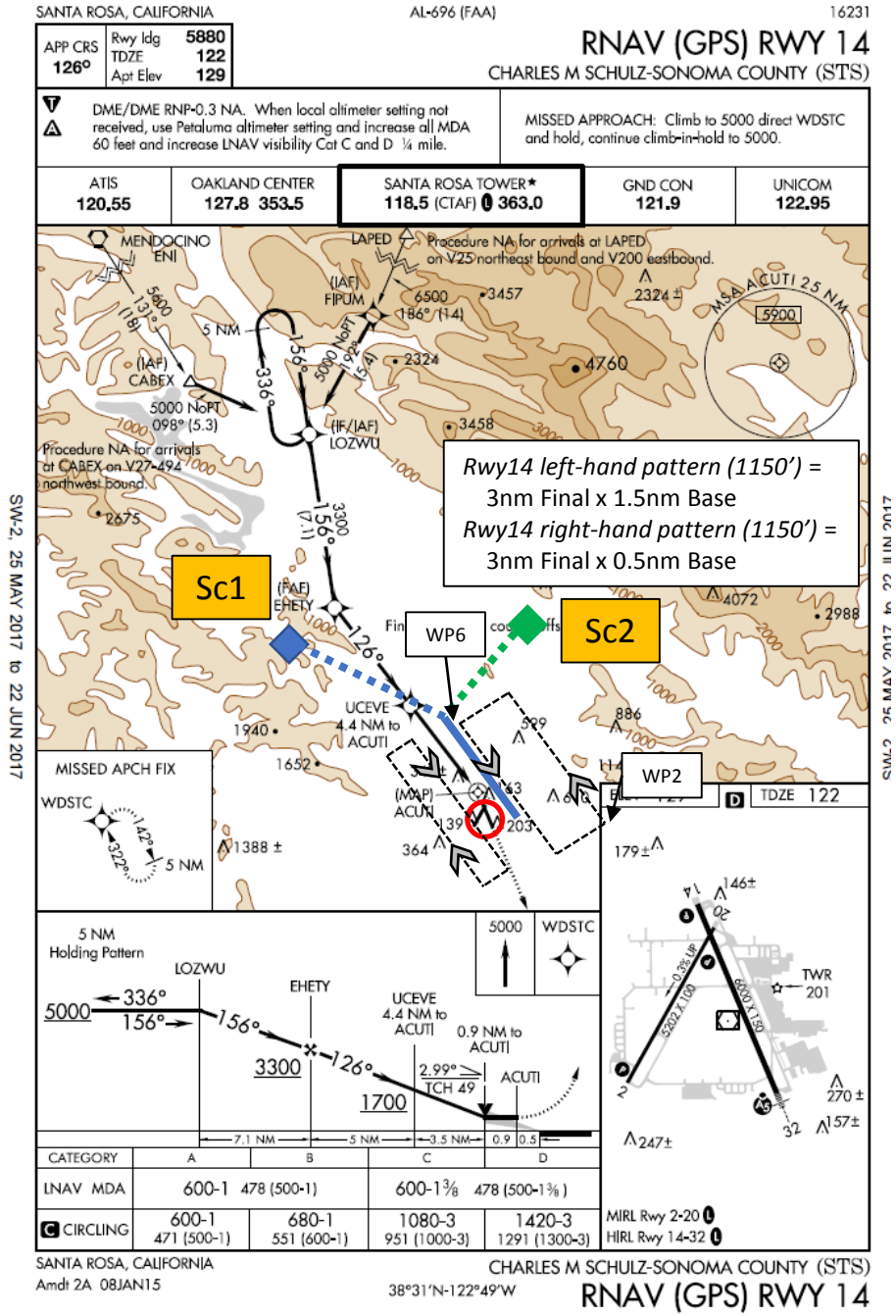
Instrument Approach Encounter Types

1. VFR overflight between LOZWU & EHETY
   a. NMAC predicted, maneuver assumed, missed approach engaged
   b. Non-NMAC LoWC (~20% penetration/3000ft HMD), maneuver unknown
2. Blunder/vector to land in front of us on final (between EHETY & runway)
   a. NMAC predicted (e.g., turns directly in front of ownship), maneuver assumed, missed approach engaged
   b. Non-NMAC LoWC (ATC vectors other aircraft, sufficient separation assumed), maneuver unknown
3. Standard approaches (no scripted conflicts)
   a. Activity in traffic pattern may set off alerts, landing assumed (x2)



Visual Approach Ownship Scenarios

- Ownship starting point:
  - Sc1: NW of WP6
  - Sc2: NE of WP6
- Initial navigation mode: HOLDS mode
- Initial control sector: ZOA40
- ATC coordination:
  1. ZOA40 vectors ownship direct to STS, terminates radar services, and sends to Tower
  2. Contact Tower, ownship provides location and requests visual approach
  3. Tower advises ownship to follow lead aircraft, eventually cleared to land
- VS interaction:
  1. Use HOLDS mode to fly toward WP6 and follow lead aircraft
  2. @ WP6 route has glide slope programmed for straight-in to Rwy14
  3. Missed approach = runway heading (direct WDSTC), climb to 5000ft



Visual Approach Encounter Types

1. Overflight blunders into us between initial point and WP6
   a. NMAC predicted, maneuver assumed
   b. Non-NMAC LoWC (~20% penetration/3000ft HMD), maneuver unknown
2. Blunder/vector to land in front of us on final (between WP6 & runway)
   a. NMAC predicted (e.g., turns directly in front of ownship), maneuver assumed, missed approach engaged
   b. Non-NMAC LoWC (ATC vectors other aircraft, sufficient separation assumed), maneuver unknown
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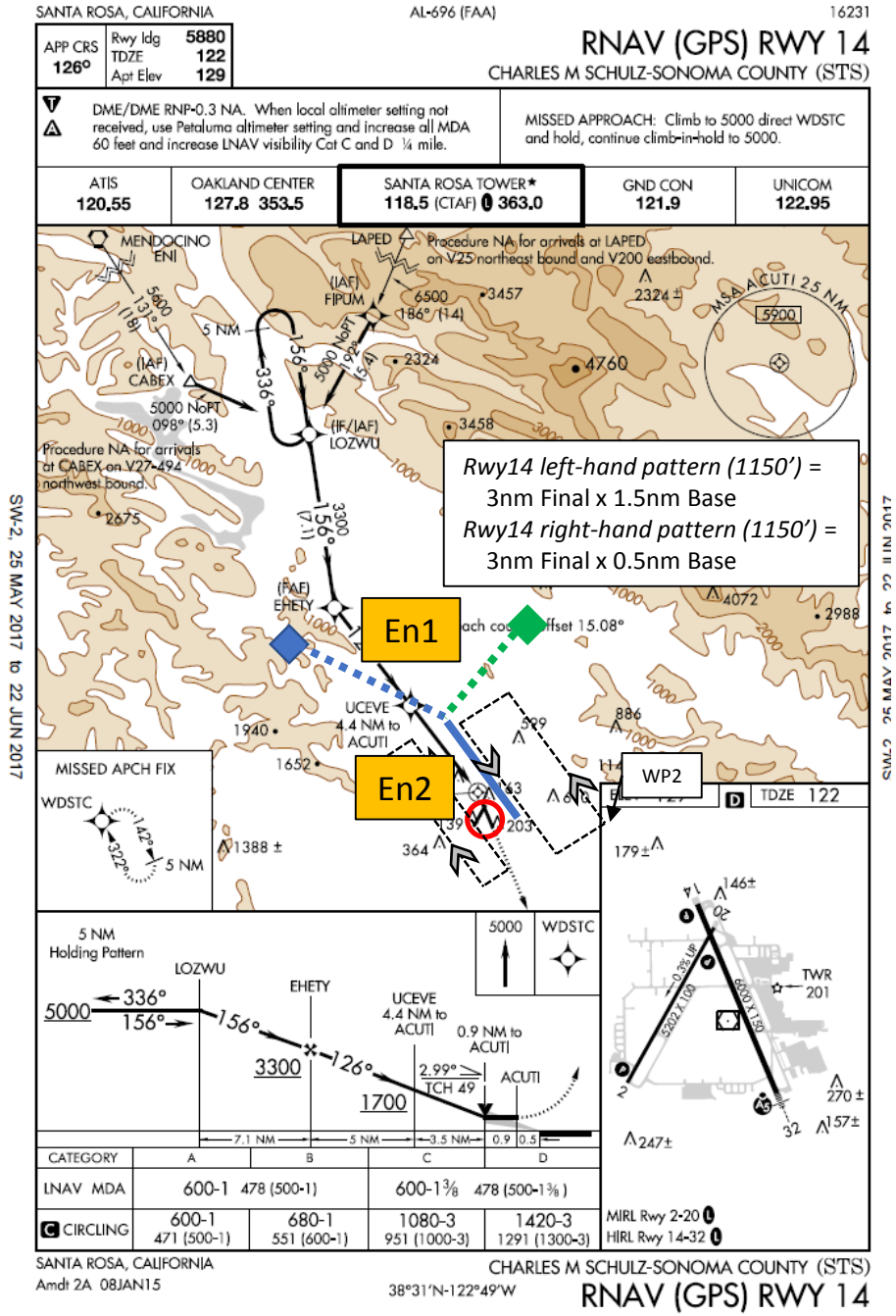
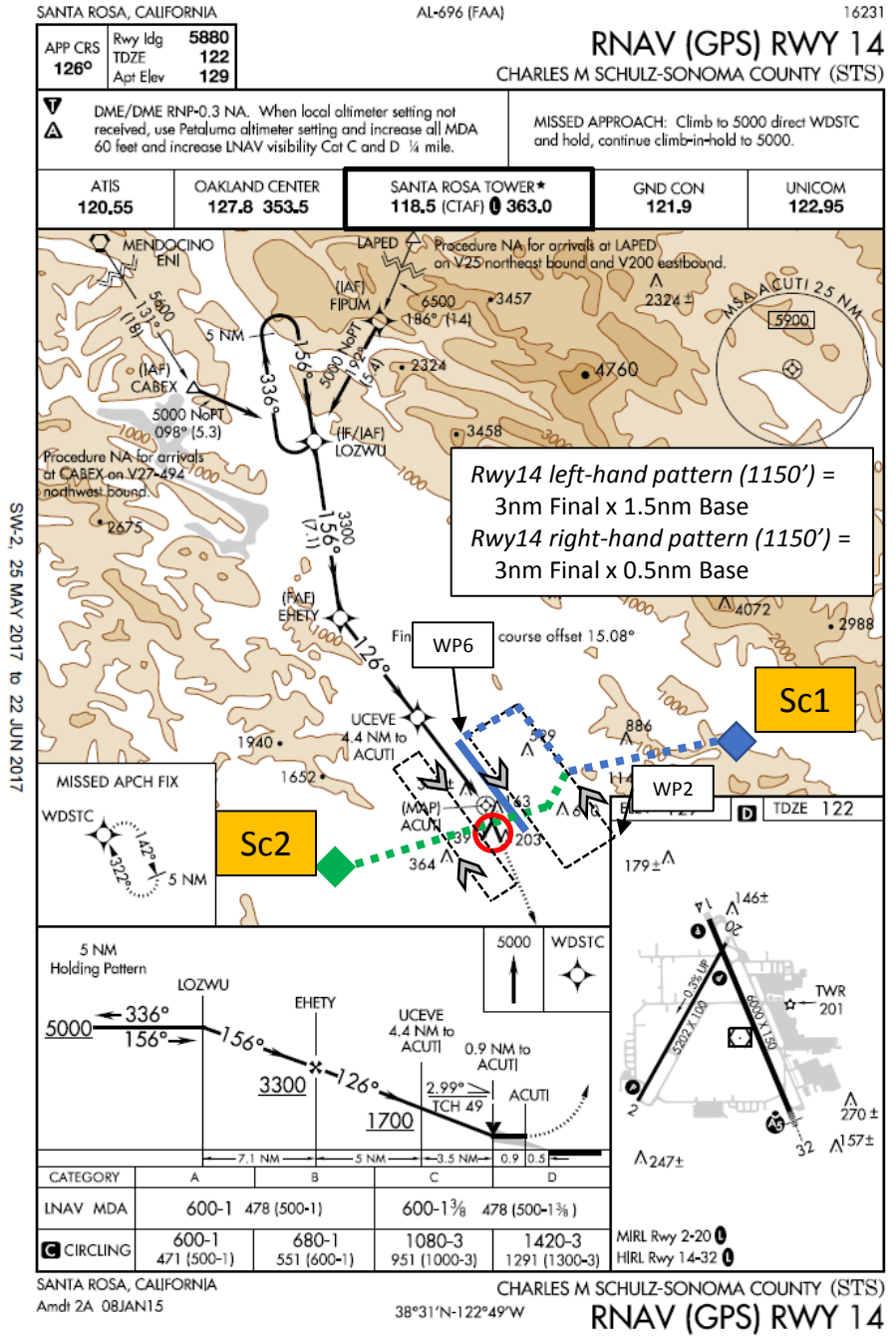


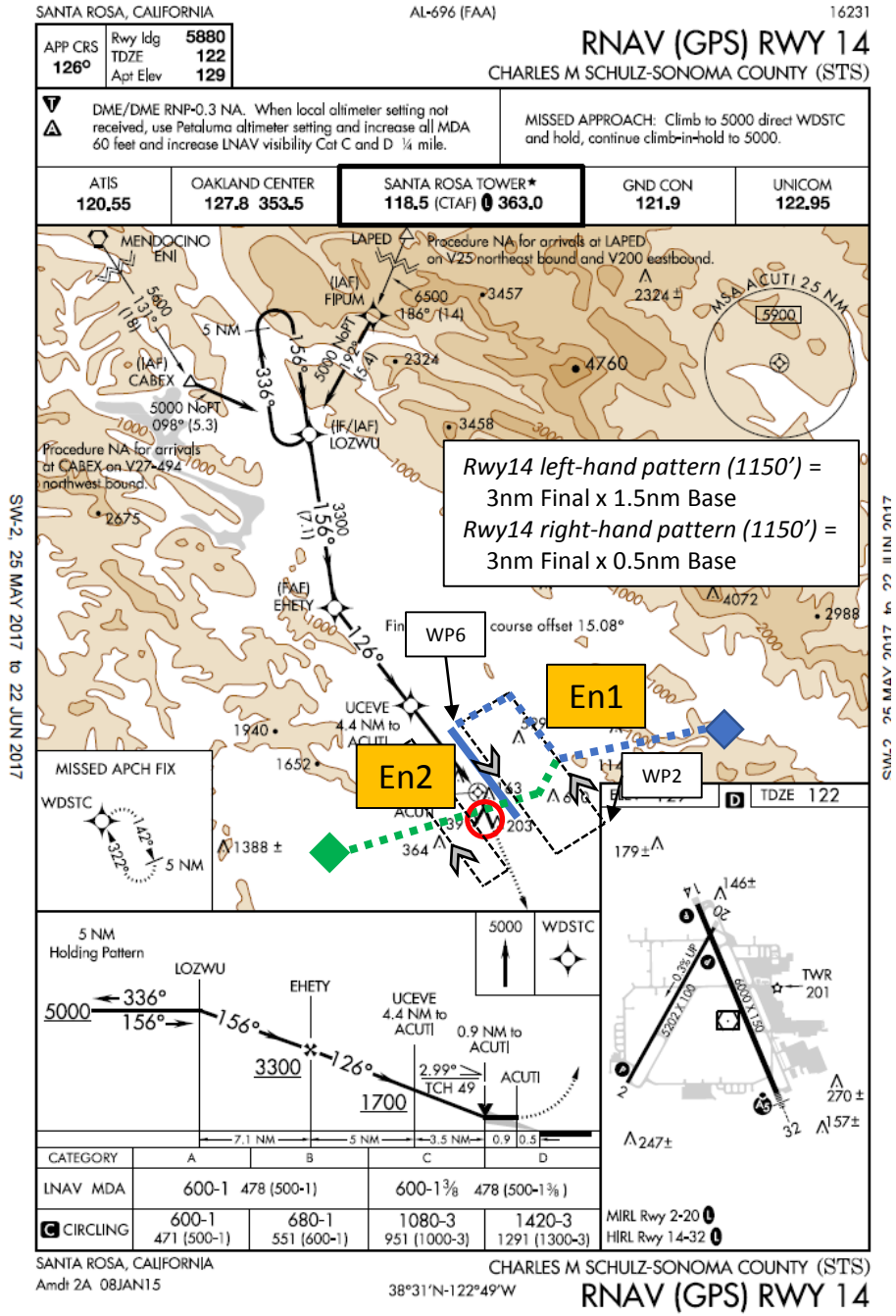
Traffic Pattern Ownship Scenarios

- Ownship starting point:
  - Sc1: E of WP2 (for 45° entry into the downwind)
  - Sc2: W of ACUTI & 500ft above pattern altitude (for mid-field entry)
- Initial navigation mode: HOLDS mode
- Initial control sector: ZOA41
- ATC coordination:
  1. Check in with Tower, ownship provides location and desired runway/location of entry
  2. Tower asks HAWK to report 2-4nm out, after which HAWK will be cleared into the down wind (or clear to land if nobody on runway)
- VS interaction:
  1. Use HOLDS mode to fly toward and enter pattern as requested
  2. @ WP6 route has glide slope programmed for straight-in to Rwy14
  3. No missed approaches – exit and re-enter pattern



Traffic Pattern Encounter Types

1. Overflight blunders into us between initial point and entry point
   a. NMAC predicted, maneuver assumed, exit and re-enter pattern
   b. Non-NMAC LoWC (~20% penetration/3000ft HMD), maneuver unknown
2. Departures blunder/vector into us as we are on final (between WP6-Runway)
   a. NMAC predicted, maneuver assumed, exit and re-enter pattern
   b. Non-NMAC LoWC (ATC vectors other aircraft, sufficient separation assumed), maneuver unknown
3. Standard pattern entry
   a. Activity in traffic pattern may set off alerts, landing assumed (x2)



Schedule Highlights

- 1st Draft scenario version – July 14
- Pilot requests/scheduling – June 15
- Stakeholder workshop – July 18/19
  - NASA only debrief morning of July 20
- Scenario refinement discussions – July 20/21
- Scenario refinement – July 24 – Aug 11
- Experiment review – Week of July 31/Aug 7(TBD)
- Shakedown – Aug 14 – Sept 1
- Data Collection – Sept 5 – Oct 2

Schedule (future HITLs)

•**Low SWaP HITL:** **(FY18)**
Experimental Design
2 OCT – 1 NOV

Programming
1 NOV – 1 FEB

Shake-down
1 FEB - 1 MAR

Data Collection
1 MAR – 2 APR

Data Analysis
2 APR – 30 MAY

Results Dissemination
30 MAY

• **ACAS Xu HITL:** **(FY18)**
Experiment Design
1 FEB – 2 APR 2018

Programming
2 APR – 2 JULY

Final Experimental Plan
2 JULY

Shake-down
2 JULY – 1 AUG

Data Collection (L2)
1 AUG – 31 AUG

Analysis
4 SEPT – 1 OCT

Results Dissemination (L2)
1 OCT

•**Flight Test 5:**
Experimental Design
2 OCT – 29 DEC (2017)

Programming/set-up/planning
2 JAN – 31 MAY (2018)

Final Input to IT&E Test Plan (L3)
1 JUN

Shake-down/System Checkout
1 JUN – 29 JUN

Data Collection (L1)
2 JUL – 31 AUG

Analysis
3 SEPT – 31 OCT

Final Report
1 NOV – 1 FEB (2019)

Results Dissemination/Briefing to 228 (L2)
15 NOV

Terminal Ops HITL Stakeholder Workshop

- Dates: July 18th/19th/20th (NASA only)
- Location: N210 Rm115 and DSRL (N243 Rm240)
- Participants:
  - Industry (GA, NGC)
  - AFRL
  - FAA (ATO, flight standards)
- Key HITL components that need to be ready:
  - Draft scenarios/encounters
  - Experimental design configurations
    - Common architecture with DAIDALUS configurations

JUNE 2017

MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
29		30		31		**1**	• End experimental design development	**2**	
5		**6**		**7**		**8**		**9**	
12		**13**		**14**		**15**	• Pilot requests/ scheduling	**16**	
19		**20**		**21**		**22**		**23**	
26		**27**		**28**		**29**		**30**	

JULY 2017

MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
3		**4**		**5**		**6**		**7**	
10	• Workshop scenario shakedown • LVC unmitigated output to Cal Analytics	**11**		**12**		**13**		**14**	• 1st Draft Scenario Version
17		**18**	• Workshop Day 1	**19**	• Workshop Day 2	**20**	• NASA-only morning brief • Scenario refinement discussions	**21**	• Scenario refinement discussions (cont.)
24	• Scenario refinement (through 11 AUG) • End programming development • IT&E integrated system V&V	**25**		**26**		**27**		**28**	
31	• Experiment review (*this week or next week*)	1		2		3		4	

AUGUST 2017

MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
31		1		2		3		4	
7	• ATC training/pretest completed	8		9		10		11	• End scenario refinement
14	• Begin shakedown	15		16		17		18	
21		22		23		24		25	
28	• Begin pretest	29		30		31		1	

SEPTEMBER 2017

MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
28		29		30		31		1	• End shakedown
4	• Holiday	5	• Begin data collection	6		7		8	
11		12		13		14		15	
18		19		20		21		22	
25		26	• Last day of data collection	27	• Backup pilots begin	28		29	

OCTOBER 2017

MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
2	• End data collection	**3**	• Begin data analysis	**4**		**5**		**6**	
9		**10**		**11**		**12**		**13**	
16		**17**		**18**		**19**		**20**	
23		**24**		**25**		**26**		**27**	• End data analysis
30		**31**		1		2		3	• Results dissemination

Terminal Ops Multi UAS Control - System Changes

PT6 System

- 2 parallel systems (2 LVC gateway, 2 VS Control station, 2 JADEM)
  - Allowed for 2 UAS in same airspace

Terminal Ops HiTL System

- Utilizing common DAA algorithm (CADASEUS)
  - DAIDALUS will be used to provide guidance and alerting (resides within JADEM Wrapper)
- Multi UAS control from one system (1 LVC gateway, 1 VS control station, 1 JADEM)
  - Researcher will cycle through vehicles via VSCS's asset panel
- Santa Rosa (KSTS) built into the MACS environment
- Surveillance Sensor Adapter (SSA)
  - Converting DAA Track State messages into MPI Flight State for MACS controller display

Development Notes

- MACS display development
  - Established airspace for the airport traffic area (5 mile range, 2600 ft AGL)
  - Frequencies
  - Terminal map
  - Tower patterns
    - Establishing waypoints at the corners for MACS and VSCS
  - Updates to ATC displays
    - Both center (updates) and tower (built from scratch) controller displays
- Start developing VSCS tracks (8 MAY)
- Start on VFR traffic patterns (8 MAY)
- Revising traffic scenario from PT6

Development Notes

- VSCS Modifications
  - Multi-UAV control at single VSCS
    - Relinquish one ownship before taking control of another
  - Commanding variable speeds
  - Waypoint-supported glide slope
  - Pre-programmed approach/take off flight plan
  - Intruder generator
  - Display vertical speed bands from DAIDALUS
- JADEM/DAIDALUS Modifications
  - Using common architecture (CADASEUS)
  - Vertical speed guidance
  - Show heading & altitude well clear recovery simultaneously
  - DAIDALUS configurations for multiple alert and guidance configurations (w/ or w/out corrective alert; w/ or w/out corrective/preventive guidance)

Logistics

- Facilities
  - ISA awaiting signatures
  - HAT lab – sim manager and participants
    - Ghost pilot will coordinate conflicts w/ MACS traffic
  - ATC lab – pseudo pilots and controllers
    - Will also record audio and generate voice logs using their SimPhonics
    - Running both 40/41 and Santa Rosa tower
    - Increasing by 1 controller and 2 pseudo (2 controllers, 5 pseudo pilots)