‘Fliegen Sie das Teleskop’

Troy Asher
Steve Cumming
Agenda

• A brief SOFIA overview
• Review of Open Cavities in Flight
• SOFIA Cavity / Door Design
• Flight Test Approach / Managing Test Points
• Flight Test Results
• SOFIA in Action
• Conclusions and Lessons Learned
Program Objectives

Further scientific knowledge in the field of astronomy and astrophysics by complementing and augmenting ground and space-based observation capabilities through development and operation of a next generation airborne observatory.
Stratospheric Observatory For Infrared Astronomy

- World’s largest flying telescope
- International Cooperative Effort between NASA and DLR
  - Aircraft Ops: NASA Dryden Aircraft Ops Facility, Palmdale, CA
  - Science/Mission Operations
    - NASA Ames Research Center, Moffett Field, CA
    - Universities Space Research Association, Columbia, MD
    - Deutsches SOFIA Institut (DSI), Universität Stuttgart
- Operational lifetime planned for 20+ years
  - Designed to operate at 39,000 to 45,000 feet
  - Above > 99% of obscuring water vapor
  - 7 different scientific instruments, initially; more to follow
- World-wide deployments: 960 science hours per year
Why Stratospheric?

Mauna Kea

SOFIA
Observatory - The Aircraft

- Boeing 747SP-21 “Clipper Lindbergh”
- Delivered to Pan Am (1977); United Airlines (1986)
- Acquired by NASA in 1997; first flight 2007
- Based at NASA Dryden Aircraft Operations Facility (Site 9), Palmdale, California
- MTOW: 696,000 lbs
- Max Alt: 45,100 ft
Observatory Layout

- Observatory Power
- Water Vapor Monitor
- Pressure Bulkhead
- Open Cavity (door not shown)
- Public Outreach Section
- Mission Director, Telescope Operators, Scientists
- TELESOCPE
- Scientific Instrument
Observatory - The Telescope

- 2.5m optical/infrared/sub-millimeter
- Built for DLR by MT Aerospace and Kayser-Threde
  - Primary mirror: "Zerodur" glass ceramic from SCHOTT AG
  - Cassegrain Focus in Nasmyth arrangement
  - +15 to +70 degrees above the horizon (full range)
  - Weight: 44,000 lbs/20,000 kg
Observatory – Science Instruments

**GREAT: German REceiver for Astronomy at Terahertz frequencies spectrometer**

When observing, GREAT will move with the telescope plus or minus 20 degrees from its normal 40-degree angle.
Infrared Astronomy

Orion in Visible Light

Orion in the Infrared

Frequency: $10^{14}$ Hz to $10^{20}$ Hz

Typical size: 10^{-8} Å to 10^{0} Å
Aerodynamics

Steve Cumming
Flying with Open Cavities

• Flying a large open cavity can be problematic
  – Cavity resonance is common
  – Severe resonance can cause structural damage or fatigue

• Large aircraft cavities often resonate at higher speeds due to Rossiter modes

• The most common solutions to dealing with resonance are an aerodynamic fence, an over-designed structure or flight envelope limitations
History of Large Cavities in Flight
SOFIA Cavity Design

• SOFIA program had several requirements that made commonly used cavity treatments undesirable
  – Provide a platform for observing over a wide range of the EM spectrum
  – Maximize time at-altitude, on-condition
• Plan was to use a shaped cavity and aft ramp to appropriately control the shear layer and minimize the probability of resonance
• To maximize the probability for success a series of wind tunnel tests were undertaken to design the SOFIA cavity
  – Testing began in 1990 and was completed in 1997
  – 5 series of 7% scale wind tunnel tests were completed
SOFIA Wind Tunnel Tests

- SOFIA I
  - Investigated cavity configurations to prevent resonance
  - Established basic flow control design
  - Several 747 variants tested
  - Forward cavity
- SOFIA II
  - 747-200, 747SP variants tested
  - Aft cavity
- SOFIA III:
  - Investigated effects of different TA model designs
- SOFIA IV:
  - Investigated aero-optical properties of candidate configurations
- SOFIA V:
  - Investigated candidate door designs
  - Tested final cavity design and configuration
SOFIA Cavity Design
Pre-Flight Analysis and Test

- Substantial testing and analysis was performed prior to SOFIA flight tests
- Aerodynamic and Acoustics tests and analyses:
  - 7% wind tunnel tests
  - 3% wind tunnel tests
  - CFD
  - Baseline flights
  - 6-DOF SOFIA airplane simulation
- Due to the extensive analyses, we had a detailed set of pre-flight predictions for acoustics and possible aerodynamic effects of the cavity
CFD Results

SOFIA Door 20 degrees - Section 46 Pressures

<table>
<thead>
<tr>
<th>Mach</th>
<th>Alpha</th>
<th>Beta</th>
<th>Stab</th>
<th>Elev</th>
<th>Alt</th>
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</thead>
<tbody>
<tr>
<td>0.600</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>27k ft</td>
</tr>
</tbody>
</table>

Cp

-0.600 -0.200 0.000 0.200 0.600 1.000

Mach 0.60, 27,000 ft, alpha = 2°, 20° door position

OVERFLOW - contours
BTWT 2220 - knobs
CFD Results

Mach 0.85, 27,000 ft, alpha = 2°, 20° door position
CFD Results

SOFIA Door 20 degrees — Section 46 Pressures

<table>
<thead>
<tr>
<th>Mach</th>
<th>Alpha</th>
<th>Beta</th>
<th>Stab</th>
<th>Elev</th>
<th>Alt</th>
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<td>0.0</td>
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<td>0.0</td>
<td>27k ft</td>
</tr>
</tbody>
</table>

Mach 0.60, 27,000 ft, alpha = 2°, 40° door position
Pre-Flight Predictions

• Predictions for cavity acoustics and stability and control effects were generally positive
• Predicted cavity acoustics were predicted to be well within design range (with some exceptions)
• Predicted stability and control effects due to the cavity were relatively small
Predicted Cavity Acoustics

Cavity Aft Bulkhead SPL vs. Mach

SPL (dB)

Mach
Predicted Airplane Stability and Control

Graph showing predicted airplane stability and control with Mach number on the x-axis and Cmde (1/deg) on the y-axis. The graph includes lines for different conditions:
- Closed
- Open, 20 deg
- Open, 40 deg
- Open, 60 deg

Legend indicates the following:
- "closed" line is black.
- "open, 20 deg" line is green.
- "open, 40 deg" line is red.
- "open, 60 deg" line is blue.

The graph is labeled with altitudes for various conditions:
- 15k ft
- 25k ft
- 35k ft
- 40k ft

The graph also has a scale for Mach number ranging from 0.4 to 1.0.
Predicted Airplane Stability and Control

Graph showing the relationship between Cn_dr (1/deg) and Mach number for different conditions:
- Closed: black line
- Open, 20 deg: green line
- Open, 40 deg: red line
- Open, 60 deg: blue line

Key altitude markers include:
- 15k ft
- 25k ft
- 35k ft
- 40k ft
Pre-Flight Technical Concerns

• Despite the extensive amount of analysis and test data, there were still serious concerns prior to open door flights:
  – The shear layer control design had not been fully proven outside of wind tunnel tests
  – Scaling issues sometimes make acoustic wind tunnel tests unreliable
  – 3% wind tunnel tests indicated there was a possibility for cavity SPL above limits
  – Predictions for stability and control effects were not considered highly reliable or accurate
  – Some aerodynamic issues, such as possible pitot-static effects were unlikely to be predicted by the available analysis methods
The set of test points selected for envelope expansion were quite substantial.

Primary drivers for envelope expansion points were acoustics, aerodynamics and S&C.

Large number of test points were driven by a couple key issues:

- Analysis limitations and blind spots
- Design of the cavity door system meant that the entire envelope had to be cleared for every configuration.
Test Plan

• **OBJECTIVE:** Certify the airplane as a public use aircraft
  – Based on Type Cert. A20WE Rev 41, Mil-Specs, and NASA best practices
  – Additional engineering & science mission requirements
  – Focus was on envelope expansion and certification of the airframe
    • Some effort to show compliance with mission requirements

• **PROGRAM GOAL:** Clear SOFIA for “Early Science”
  – Short Science: ≥ 35,000 ft MSL and telescope up to 40° elevation
  – Basic Science: > 41,000 ft MSL and telescope full range (58.3°)

Program at risk due to immanent funding loss
Rigid NASA and DLR HQ Milestones
Test Plan Development

• Airworthiness testing
  – Performance
  – Flying/Handling qualities
  – Model validation
  – Demonstration of satisfactory structural characteristics
  – Flutter
  – Ground Vibration Test (GVT) to validate/update FEM

• Major Test Disciplines involved
  – Aerodynamics (incl. acoustics)
  – Stability & Control
  – Structural Dynamics (Flutter)
  – Static Structures (Loads)
  – Door Drive System
  – Science
  – Operations
  – Telescope
Test Point Selection

• Concentrate on areas not modeled or wind tunnel tested
• Risk of *acoustic resonance* drove check of multiple door/aperture positions
  - 10%, 40%, 70%, 100% Open – Door could be moved in flight
  - 23°, 30°, 40°, 50°, 58° Aperture – Set prior to flight

• No data for door open landing configuration
• Include ‘Contingency’ test points to cover any unknowns
### Envelope Expansion

#### Types of Test Points

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Type</th>
<th>Maneuver</th>
<th>URD Position</th>
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<tbody>
<tr>
<td>Aerodynamics</td>
<td>Steady State</td>
<td>Trim shot</td>
<td>Closed, open</td>
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<tr>
<td></td>
<td>Pitot-statics</td>
<td>Accel/decels</td>
<td>Closed, open</td>
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<tr>
<td></td>
<td></td>
<td>Tower fly-bys</td>
<td>Closed</td>
</tr>
<tr>
<td></td>
<td>FADS Cal</td>
<td>PUPO, rudder sweeps</td>
<td>Closed, open</td>
</tr>
<tr>
<td></td>
<td>PID</td>
<td>Pitch, roll, yaw, yaw-roll doublets, Wind-up turns</td>
<td>Closed, open</td>
</tr>
<tr>
<td></td>
<td>Vibration and buffet</td>
<td>Straight &amp; level flight, maneuvering flight</td>
<td>Closed, open</td>
</tr>
<tr>
<td>S&amp;C</td>
<td>Static lat-dir stability</td>
<td>Straight, steady sideslips, $V_{mca}$, 2-Eng go</td>
<td>Open</td>
</tr>
<tr>
<td>Dynamics</td>
<td>Flutter</td>
<td>Raps</td>
<td>Closed, open</td>
</tr>
</tbody>
</table>

FADS = Flush Air Data System
Initial SOFIA Flight Envelope

- **MLE/VLE** = Maximum demonstrated flight dive speed
- **Mmo/Vmo** = 0.87M/340 KEAS
- **MFC/VFC** = 0.90M/360 KEAS
- **MDF/VDF** = 0.92M/VMO +30 KTS

**V_{DF}/M_{DF}** = Maximum demonstrated flight dive speed

**V_{FC}/M_{FC}** = Maximum airspeed for stability characteristics
Initial Open Door Test Conditions

- Short Science Min Altitude
- MLE/VLE 0.82M/320 KCAS
- MMO/VMO 0.87M/320 KCAS
- MFC/VFC 0.90M/340 KCAS
- MDF/VDF 0.92M/350

- VDF = maximum demonstrated flight dive speed
- VFC = maximum airspeed for stability characteristics

- VDO/MDF = maximum demonstrated flight dive speed
- VFC/MFC = maximum airspeed for stability characteristics
## Final Test Point Count

<table>
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<tr>
<th>Category</th>
<th>Planned</th>
<th>% Pts</th>
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<tbody>
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<td>48%</td>
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<tr>
<td>AERO/S&amp;Co</td>
<td>1314</td>
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<tr>
<td>Total Aero</td>
<td>2788</td>
<td>91%</td>
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<tr>
<td>S&amp;Co</td>
<td>44</td>
<td>1%</td>
</tr>
<tr>
<td>CDDS</td>
<td>2</td>
<td>0.1%</td>
</tr>
<tr>
<td>Ops</td>
<td>4</td>
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</tr>
<tr>
<td>Science</td>
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</tr>
<tr>
<td>Static Structures</td>
<td>5</td>
<td>0.2%</td>
</tr>
<tr>
<td>Struct Dynamics</td>
<td>202</td>
<td>7%</td>
</tr>
<tr>
<td>TA</td>
<td>15</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

**Total Test Points**: 3067 100%
Challenges

• Primary mirror already installed
  – Sun cover
  – Contamination
  – Thermal conditioning
• No test software load
  – Designed to always open door to 100%
  – “Manual Control” for intermediate positions
• Separate flight for each aperture setting
• Instrumentation batteries only good for 6 hours
• “Ride-along” testing for Early Science
Reality Strikes

• “You have too many test points!”
• Defining the problem
  – Milestones: “First Light” & “Initial Science” (ISF)
  – 6 hour flights determine max test points/flight
  – Data analysis/inspections drive fly rate

Estimated test capacity: 1000 test points
The Approach

• “Schedule for Success” but plan for the worst
• Optimistic assumptions vs. flight test results
  – Assume **best-case** technical results from flight test
  – If test results validate models, skip ahead but spot check
    • Fly 23° aperture at all test conditions
    • Fly 40° aperture at a reduced set of test conditions
    • Go back and spot check 30° aperture
• Publish a “Success Oriented” Schedule, **BUT**
• If **any** optimistic assumptions are inaccurate, more test points will be flown to investigate...schedule will slip
• Not all optimistic assumptions expected to be accurate
Reduced Airspeed Envelope

Inclines misaligned TA

\[ M_{\text{Mo}} 0.87 \text{ Mach} \]

\[ \text{TA/AA } 23^\circ \text{ and URD } 100\% \]
DER Recommendations

- Consulted with FAA Designated Engineering Representatives on adequacy of test plan
  - 15 items suggested for deletion from test plan
  - 9 items suggested to add to test plan
  - Majority of suggestions incorporated
Open Door Envelope Expansion Approach

- **MLE/VLE**: 0.82M/320 KCAS
- **MMO/VMO**: 0.87M/320 KCAS
- **MFC/VFC**: 0.90M/340 KCAS
- **MDF/VDF**: 0.92M/350 KCAS

Legend:
- VFE = Flying Envelope Expansion
- VLO = Level Off
- VA = Max Airspeed for Stability Characteristics
- VLE = Max Lift Envelope Expansion

**V_{DF}/M_{DF}** = maximum demonstrated flight dive speed

**V_{FC}/M_{FC}** = maximum airspeed for stability characteristics
Test Point Sequence

• Clear Aero, Acoustics, S&C and Flutter I.T.B.s
• Performance, buffet boundary and systems
• Open Door Landing
  – Plan one open door landing in worst-case configuration
  – No wind tunnel or analytical data for ground effect case
  – KAO had an unexpected acoustic event during flight test in the landing flare
Flight Test Results

• Final results exceeded expectations
• Found NO substantial or consistent effects on stability and control
• Sound pressure levels in the cavity were below expected values
• Handling qualities not degraded
• Flies like a stock 747
Cavity Acoustics

Cavity Aft Bulkhead SPL vs. Mach

- Actual - 15 kft
- 7% Theo. - 15 kft
- Actual - 25 kft
- 7% Theo. - 25 kft
- Actual - 35 kft
- 7% Theo. - 35 kft

SPL (dB)

Mach
Cavity Acoustics

Normalized $P_{\text{rms}}$ vs. Mach

- Cavity Aft Bulkhead
- 7% Wind Tunnel

- $P_{\text{rms}}$ in qbar
- Mach range: 0.2 to 1

Graph showing data points and trend lines for Cavity Aft Bulkhead and 7% Wind Tunnel.
Stability and Control Results

![Graph showing Stability and Control Results](image)
Stability and Control Results

![Graph showing stability and control results with Mach number as the x-axis and C_n_dr as the y-axis. The graph includes data points for different percentages (10%, 40%, 95%) and legends for URD and AA with specific values for each.]
• G-overshoots during Wind-up turns
• Steady-heading-sideslips at low speed
• Stuck door landings
First 100% Door Open

Dryden Flight Research Center

SOFIA 747SP
SOFIA 747SP open door flight fully exposes infrared telescope for the first time
December 18, 2009
## Final Score

<table>
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<tr>
<th>Category</th>
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<th>Flown</th>
<th>Saved</th>
<th>% Redux</th>
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<tr>
<td>AERO</td>
<td>1474</td>
<td>48%</td>
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<td>996</td>
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<tr>
<td>AERO/S&amp;C</td>
<td>1314</td>
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<tr>
<td>Total Aero</td>
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<td>31</td>
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<td>1</td>
<td>7%</td>
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<tr>
<td>Test Points</td>
<td>3067</td>
<td>100%</td>
<td>865</td>
<td>2202</td>
<td>72%</td>
</tr>
</tbody>
</table>
The Most Common Question

• Q: What do you feel when the door opens?

• A: NOTHING!

If you didn’t know the door was open through instrumentation and systems operating, you wouldn’t even notice it.
“First Light” Image of Jupiter
May, 2010

Visible light image

SOFIA infrared image (5.4, 24, and 37 \( \mu m \))
Images from SOFIA

Heart of Orion Nebula

Graphical representation comparing two infrared images of the heart of the Orion nebula captured by the FORCAST camera on SOFIA with a wider image of the same area from the Spitzer space telescope.

SOFIA image -- James De Buizer / NASA / DLR / USRA / DSI / FORCAST; Spitzer image -- NASA/JPL

Planetary Nebula M2-9

The last exhalations of a dying star

W40

Mid-infrared image of the W40 star-forming region of the Milky Way captured by FORCAST
NASA / FORCAST image, May 18, 2011
GREAT collected its first THz photons from the M173W star forming cloud April 6, 2011. Superimposed on a near-infrared false-color image measured by the Spitzer Space Telescope are selected spectra of ionized carbon (CII) and warm carbon monoxide (CO). The high spectral resolution of GREAT is used to study the velocity structure across the cloud.

April 6, 2011
(GREAT Team/NASA/DLR/USRA/DSI)
Mid-IR image of Orion Messier 42
Star-forming Region
W3 Star-forming Region

Mid-infrared image of the W3A star cluster (inset) captured by FORCAST in 2011. Image overlaid on a near-infrared image from the Spitzer space telescope. The SOFIA image scale is 150x100 arcseconds and the red, green and blue colors represent 37, 20 and 7 μm. The red, green and blue colors in the background image from Spitzer represent 7.9, 4.5, 3.6 μm.

SOFIA image: NASA / DLR / USRA / DSI / FORCAST team
Spitzer image: NASA / Caltech - JPL. 2011
Stellar Occultation by Pluto

- **Proof of Concept**: First test of a ‘time sensitive’ operation
- **Observational Objectives**
  - Observe Occultation Central Flash
  - Observe Pluto lightcurve at high SNR
  - Observe Pluto/Charon joint occultations
  - Observe Pluto/Star separated photometry with HIPO
- **Science Objectives**
  - Measure Atmospheric Asymmetry (wind distortion?)
  - Measure Atmospheric Profile (Pressure/Temp vs. Alt)
  - Measure Atmospheric Size (Rising trend reversing?)
  - Identify Pluto Ephemeris Errors (Future events and New Horizons)
- **Operations Objectives**
  - Safely fly a very long mission and return to Palmdale
  - WHAT ABOUT A STUCK DOOR??
Planetary Science: Occultations

SOFIA is able to:

- Go anywhere on Earth to reach the occultation shadow of an object
- Can probe the sizes, structures (rings & moons), and atmospheres of solar system bodies by measuring how they occult background stars
- This will be the primary objective for HIPO (High-speed Imaging Photometer for Occultations)
Returning to PMD with open door

True headings back to Palmdale from the URD decision point are:

a) default flight plan 23° to 26°
b) alternative flight plan 28° to 32°

=> No in-flight concern with catching sunlight, because TA is facing north-west
Palmdale

Sunrise

10 am, EL of the sun is 50°

Sun Avoidance angle at Sunrise

40° Sun Avoidance angle at 10 am

Sun elevation needs to be considered between 9:30 am and 4:15 pm

Landing RWY 25 before 11 am is not a factor

40° Sun Avoidance angle given before 4 p.m.
In case of a Go-around in PMD only a ‘figure 8’ pattern is possible to reposition to a suitable runway.
Stellar Occultation by Pluto
July 23, 2011

- Dwarf planet Pluto (V~14) occulted a star (V~14.4)
- SOFIA met the shadow of Pluto in mid-Pacific
- HIPO (Lowell Obs.) and FDC (DSI) instruments observed the occultation simultaneously

Image sequence from the Fast Diagnostic Camera (FDC)

Pluto (circled) is 13 arcsec from the star 200 minutes before the occultation.
Just before occultation: Pluto and star merged, combined light!
**During occultation:** Pluto and star merged, only Pluto light seen
After occultation: Pluto and star merged, combined light!
Conclusions/Lessons Learned

1. “Do Your Homework”
   - An investment in baseline, wind tunnel, and ground testing as well as engineering analysis pays large dividends

2. “Schedule for Success, Plan for the Worst”
   - This is more effective if #1 above was sufficiently done
   - Use all tools available to analyze necessary testing
   - Leave plenty of “off ramps” for unknown events

3. Have a Flight Test version of your software
   - Increases test effectiveness
   - May help avoid unknown effects
Backup
Build-Up to Open Door
Envelope Expansion

$V_{DF}/M_{DF}$ = maximum demonstrated flight dive speed

$V_{FC}/M_{FC}$ = maximum airspeed for stability characteristics
Current best estimate of shadow centerline

1-sigma uncertainty position of north edge of Pluto’s shadow

Current best estimate of north edge of Pluto’s shadow

Current best estimate of north edge of Pluto’s shadow

1-sigma uncertainty position of south edge of Pluto’s shadow

There is still considerable uncertainty in the location of the occultation track. Work to improve this is in progress, but just started. The Sun was in the way of Pluto observations for the last several months and we could only start this work a couple of weeks ago.

The sun is up, or in bright twilight, in the unshaded area here.

Hawaii
Kona is 2201 NM From PMD
Time - 4:31

Inside this circle Pluto is too high in the sky - above the upper elevation limit for the door.

Pluto is this big

Or it might be here

Outside this circle Pluto is too low in the sky - below the lower elevation limit for the door.

It might be here
In case of an open URD event: landing in HIK is approx. at sunrise
Assuming that CD Dampers will be removed a.s.a.p. after landing and TA will be rotated to 0°:
- Sun Avoidance Angle in elevation will be 0° + 40° = 40° (red line)
- No on ground concern with catching sunlight elevationwise between 9 am and 5 pm
- Even with TA in lowest elevation without removing CD Dampers EL=17° (yellow line) the morning hours 9-11 am are not a concern, because TA is facing west (SOFIA’s true heading while parking needs to be 0° +/- 20°)
There are different options to reach U as final position for engine shut down in PMD:
• straight in approach RWY 07
• straight in approach RWY 04
• before 11 a.m. only: left pattern to RWY 25, taxiing B, A, E

There are different options to reach DFRC as final position for engine shut down in EDW:
• straight in approach RWY 04, taxiing B or C, F, E
• before 9 a.m. only: left pattern to RWY 22, taxiing B or A, E, F
Pilot’s in-flight short reference card (1)

**True** HDGs back to Palmdale from the URD decision point are between 023° and 032°

- No enroute concern with catching sunlight, because TA is facing northwest

- Whatever TA elevation, aircraft **TRUE** headings **verboten** in air or on ground are between 110°T and 225°T (general statement valid before 18 UTC = 11 PDT)

  or in other words:

- True headings **allowed** in air or on ground are between 226° and 109° (general statement valid before 18 UTC = 11 PDT)

**SUN AVOIDANCE** **override** other Open Door Mission Rules to prevent condensation on TA optics/electronics like gradual descent or mirror warm-up holds.
Flight Crew should declare an In-Flight-Emergency when back in VHF Air Traffic Control range, because of limited HDG range (inability of flying all HDGs, e.g. holding patterns or 360s impossible)

PMD: (max. SOFIA tailwind component is 10 kts)

There are 3 different options to reach Taxiway U as final position for engine shut down:

- straight in approach RWY 07, taxi to taxiway U, **park aircraft with 080° true heading** (preferred – easy taxi and easiest go-around)

- straight in approach RWY 04, taxi via E to U, **park aircraft with 080° true heading** (second – easy taxi but longer go-around)

- before **11 a.m. only**: two ~90° left turns allowed,
  1) left turn into left base to final RWY 25 (= 265° true HDG)
  2) left turn into final RWY 25, taxiing via B, A, E to U, **park aircraft with 080° true heading**
Pilot’s in-flight short reference card (3)

In case of a Go-around in PMD, consider a diversion to EDW (depending on local time, RWY 22 in EDW is only an option before 10 am PDT)

**EDW:** (max. SOFIA tailwind component is 10 kts)

There are two options to reach DFRC as final position for engine shut down:

- straight in approach RWY 04, taxiing B or C, F, E to DFRC
  park aircraft with 80° true heading

- before 10 a.m. only: two ~90° left turns allowed,
  1) left turn into left base to final RWY 22 (= 237° true HDG)
  2) left turn into final RWY 22, taxiing via B or A, F, E to DFRC
  park aircraft with 80° true heading
Pilot’s in-flight short reference card (4)

In case of a Go-around in PMD, consider a diversion to EDW (depending on local time, RWY 22 in EDW is only an option before 10 am PDT)

If go-around in PMD was RWY 04 or RWY 07:
RWY 22 in EDW is recommended due to timing issues (see map next slide)

- before 10 a.m. only: two ~90° left turns allowed,
  1) left turn into left base to final RWY 22 (= 237° true HDG)
  2) left turn into final RWY 22,
  taxiing via B or A, F, E to DFRC
  park aircraft with 80° true heading