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A risk-based approach to planning aircraft acquisitions in a warming climate

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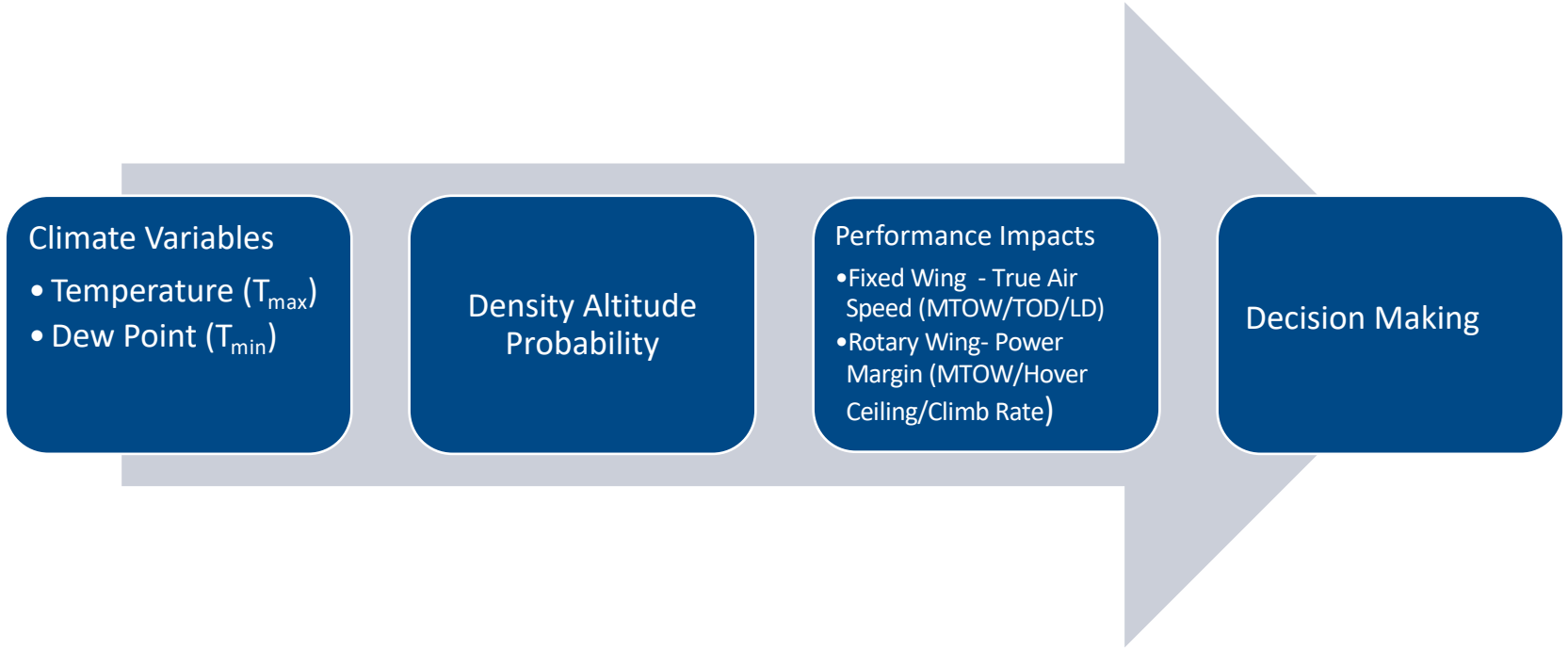
SYMPOSIUM
2018 | Enhancing DoD's Mission Effectiveness

Objectives

1) How to access and analyze climate model data that will be used to assess aircraft performance impact.

2) How air temperature and dew point projections due to climate change will comprehensively affect aircraft performance.

3) How to translate these climate projections and performance impacts into a viable decision making tool.


Climate Variables
• Temperature (T_{max})
• Dew Point (T_{min})
Density Altitude Probability
Performance Impacts
•Fixed Wing - True Air Speed (MTOW/TOD/LD)
•Rotary Wing- Power Margin (MTOW/Hover Ceiling/Climb Rate)
Decision Making

Climate Variables
• Temperature (T_{max})
• Dew Point (T_{min})
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Decision Making

Why T_{max} and T_{min}?

- **Density Altitude** is formally defined as "pressure altitude corrected for nonstandard temperature variations."
- A high density altitude means that air density is reduced, which has an adverse impact on aircraft performance.
- Data Needed:
  - **Air Temperature:** The warmer the air, the less dense it is.
  - **Altitude (station pressure):** The higher the altitude, the less dense the air.
  - **Humidity (dew point):** more water vapor in the air, the air has less mass, therefore less dense.

Estimating Surface Humidity from T_{min}

Kimball et al, Agriculture and Forest Meteorology (1997)

- If annual precipitation > 30% of annual potential evapotranspiration then can use T_{min} as surrogate for estimated dew point ($T_{d,est}$)

- If annual precipitation < 30% of annual potential evapotranspiration then use:

$$T_{d,\,est} = T_{min}\,[-0.127 + 1.121\,(1.003 - 1.444\,EF + 12.312\,EF^2 - 32.766\,EF^3) + 0.0006\,(T_{max} - T_{min})]$$

  - Evapotranspiration Factor (EF) is a non-dimensional ratio of the daily potential evapotranspiration (PET) divided by the annual precipitation.

CMIP5 multi-model ensemble: Downscaled and Bias Corrected

"Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archive at https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/.

Modeling Center (or Group), Country	Institute ID	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS 1.0
Beijing Climate Center, China Meteorological Administration, China	BCC	BCC-CSM1.1
Canadian Centre for Climate Modelling and Analysis , Canada	CCCMA	CanESM2
National Center for Atmospheric Research, USA	NCAR	CCSM4
Community Earth System Model Contributor	NSF-DOENCAR	CESM1-BGC
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique , France	CNRMCERFACS	CNRM-CM5
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence , Australia	CSIRO-QCCCE	CSIRO-Mk3.6.0
NOAA Geophysical Fluid Dynamics Laboratory, USA	NOAA GFDL	GFDL-CM3 GFDL-ESM2G GFDL-ESM2M
Institute for Numerical Mathematics, Russia	INM	INM-CM4
Institut Pierre-Simon Laplace, France	IPSL	IPSL-CM5A-LR IPSL-CM5A-MR
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	MIROC	MIROC5
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan	MIROC	MIROC-ESM MIROC-ESM-CHEM
Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology), Germany	MPI-M	MPI-ESM-LR MPI-ESM-MR
Meteorological Research Institute, Japan	MRI	MRI-CGCM3
Norwegian Climate Centre, Norway	NCC	NorESM1-M

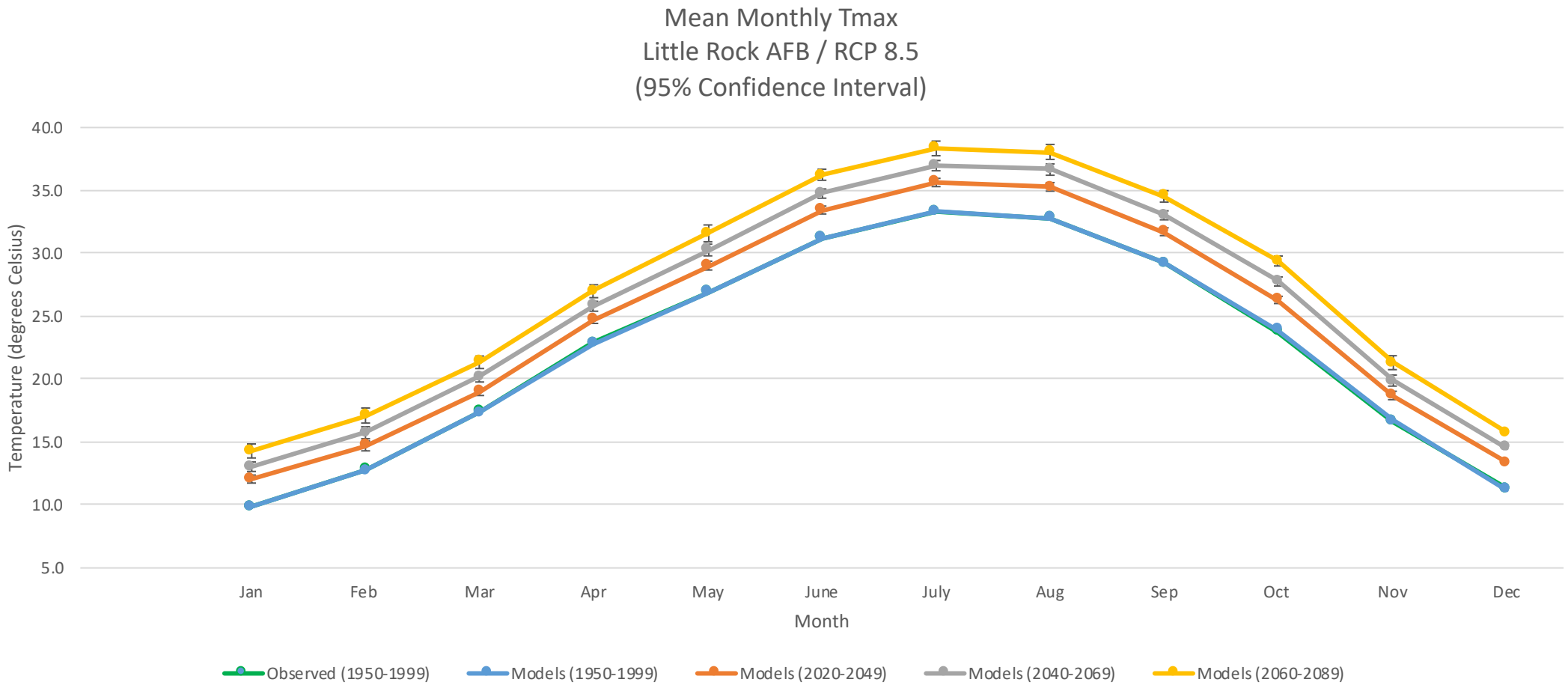
Scenario

- Location: Little Rock Air Force Base, Arkansas
  - Resolution: 1/8° latitude-longitude (~ 12km by 12 km)

- Time Period = 30 years
  - 1970 - 1999
  - 2020 - 2049
  - 2040 - 2069
  - 2060 - 2089

- Representative Concentration Pathway (RCP) = 8.5 – High Emissions
  - This RCP is consistent with a future with no policy changes to reduce emissions. It was developed by the International Institute for Applied System Analysis in Austria and is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time.
  - This future is consistent with:
    - Three times today's CO2 emissions by 2100
    - Rapid increase in methane emissions
    - Increased use of croplands and grassland which is driven by an increase in population
    - A world population of 12 billion by 2100
    - Lower rate of technology development
    - Heavy reliance on fossil fuels
    - High energy intensity
    - No implementation of climate policies

Observed & Projected T_{max}



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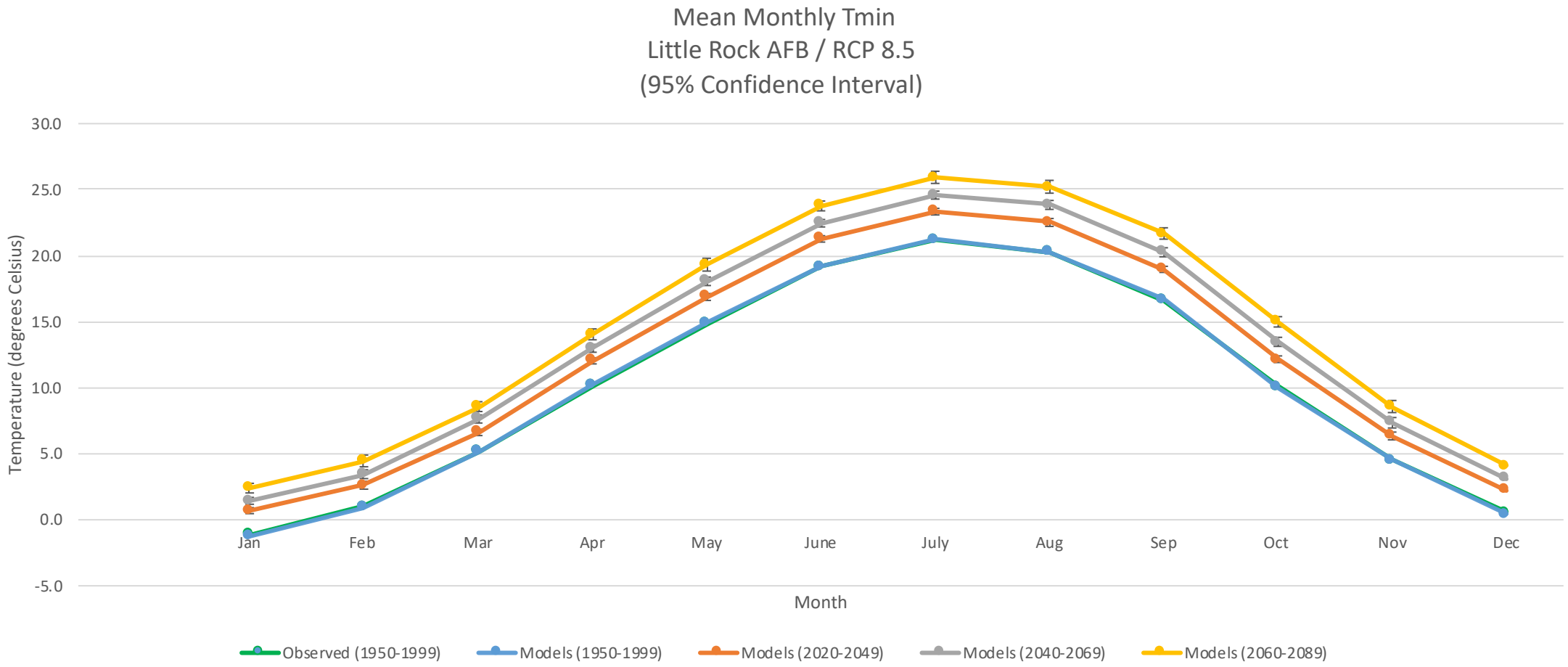
Observed & Projected T_{min}



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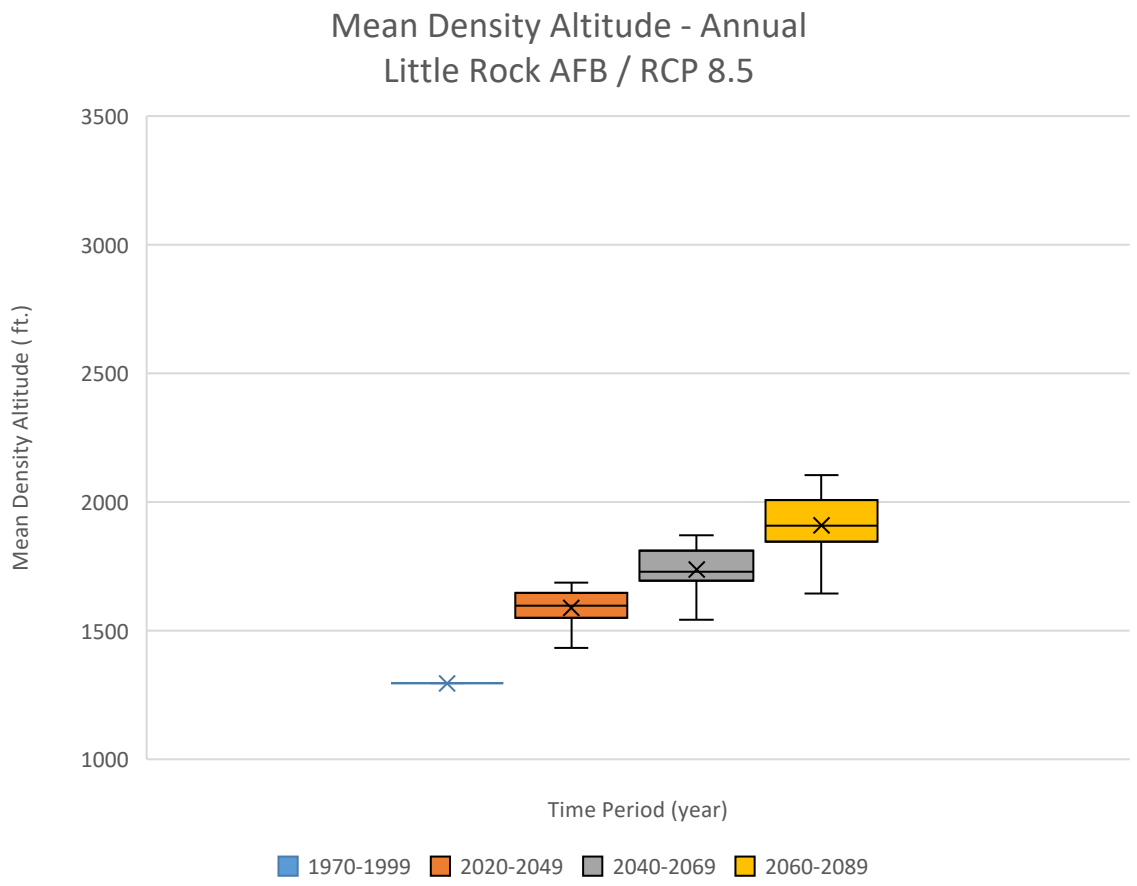
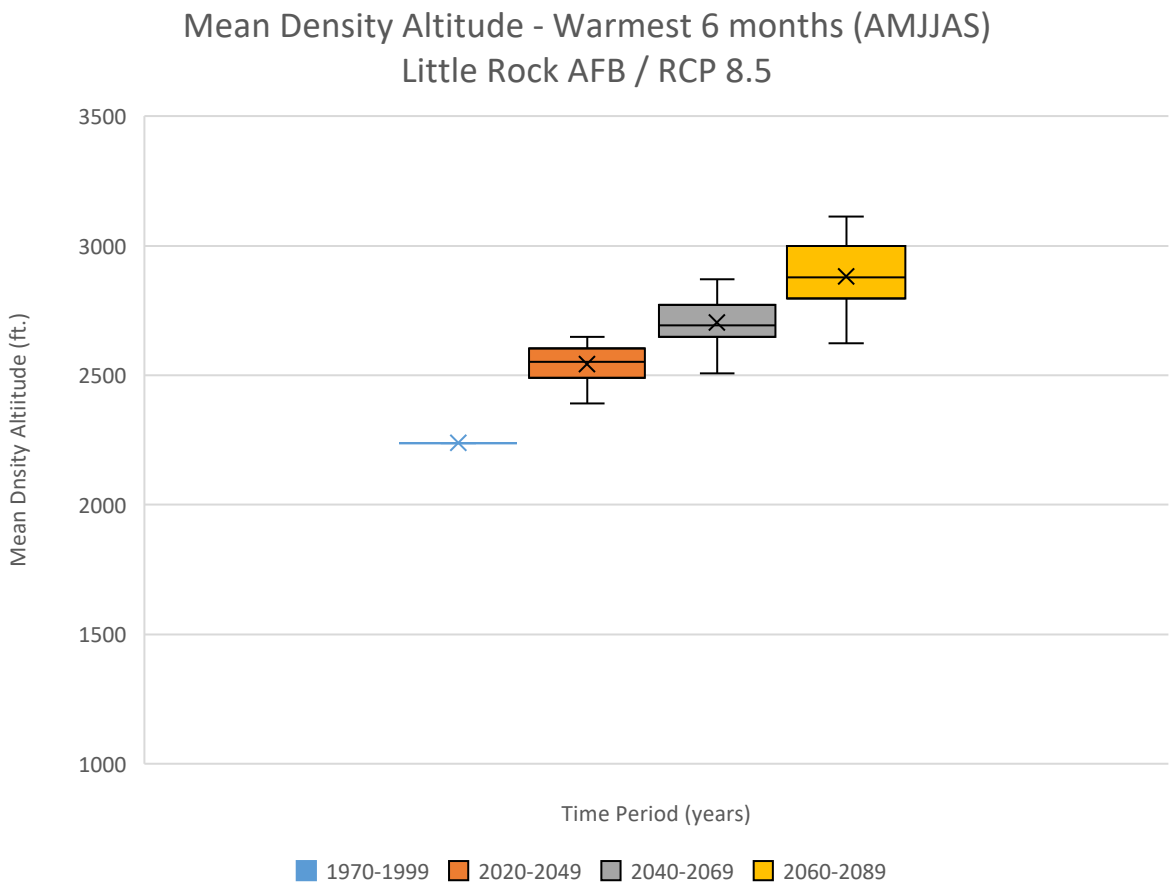
Density Altitude Thresholds are reached at lower air temperature (T_{max}) when Dew Point (T_{min}) is included

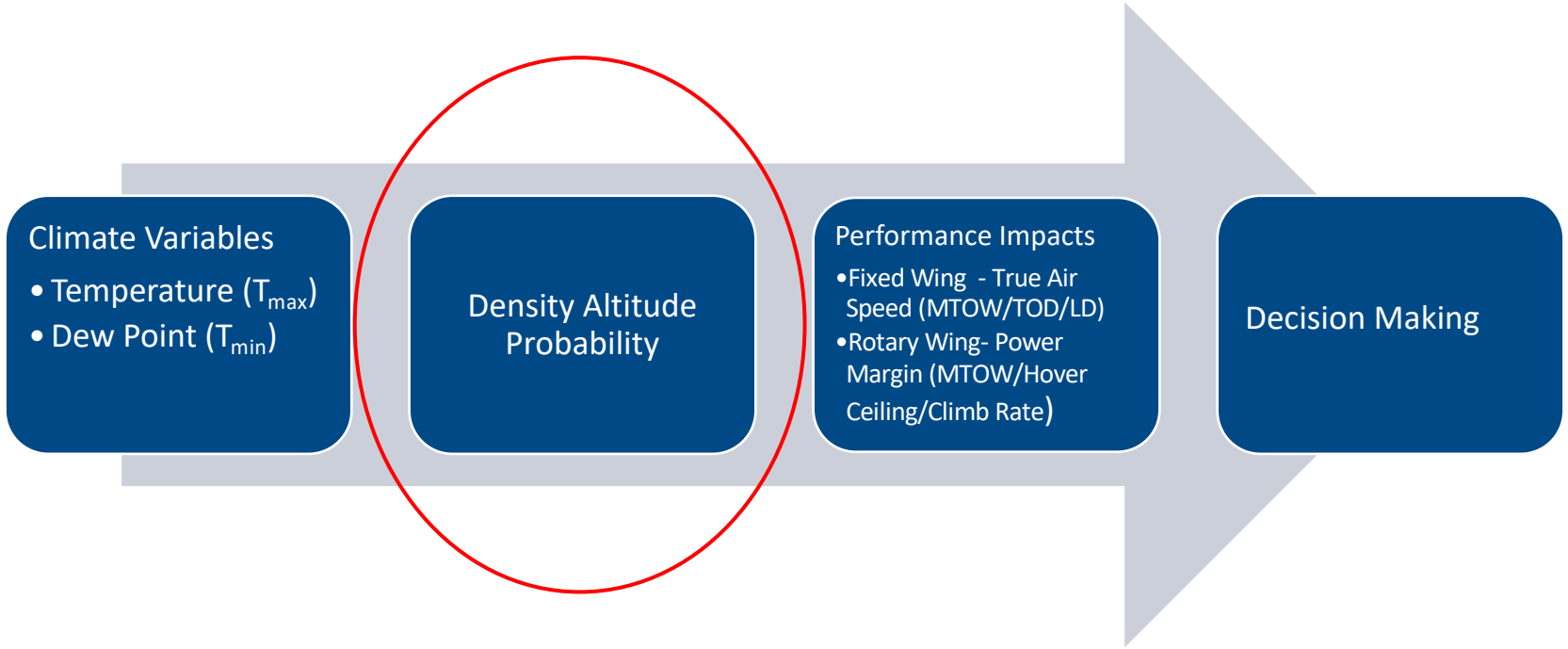
Density Altitude Threshold (1003mb)	Dry Value T_{max} (°C)	+	Include Moist Value Equivalent T_{max} (°C)	Dew Point (T_{min} , °C)
≥ 500 ft.	≥ 17		= 16 = 15 = 14	≥ -19 ≥ 8 ≥ 17
≥ 1500 ft.	≥ 25		= 24 = 23 = 22	≥ 2 ≥ 14 ≥ 21
≥ 2500 ft.	≥ 34		= 33 = 32 = 31 = 30	≥ 2 ≥ 14 ≥ 21 ≥ 26
≥ 3000 ft.	≥ 39		= 38 = 37 = 36 = 35 = 34	≥ -8 ≥ 10 ≥ 18 ≥ 24 ≥ 28

Include dew point to realize full spectrum of density altitude impacts.

Mean Moist Density Altitude



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Decision Making

Climate Data

Assess Current Capabilities
Gap Analysis
Identify operational performance requirements
Establish performance parameters

- **Density Altitude Performance Threshold**
- **Aircraft Specific Performance Threshold**

Performance Data

Comparison of Thresholds

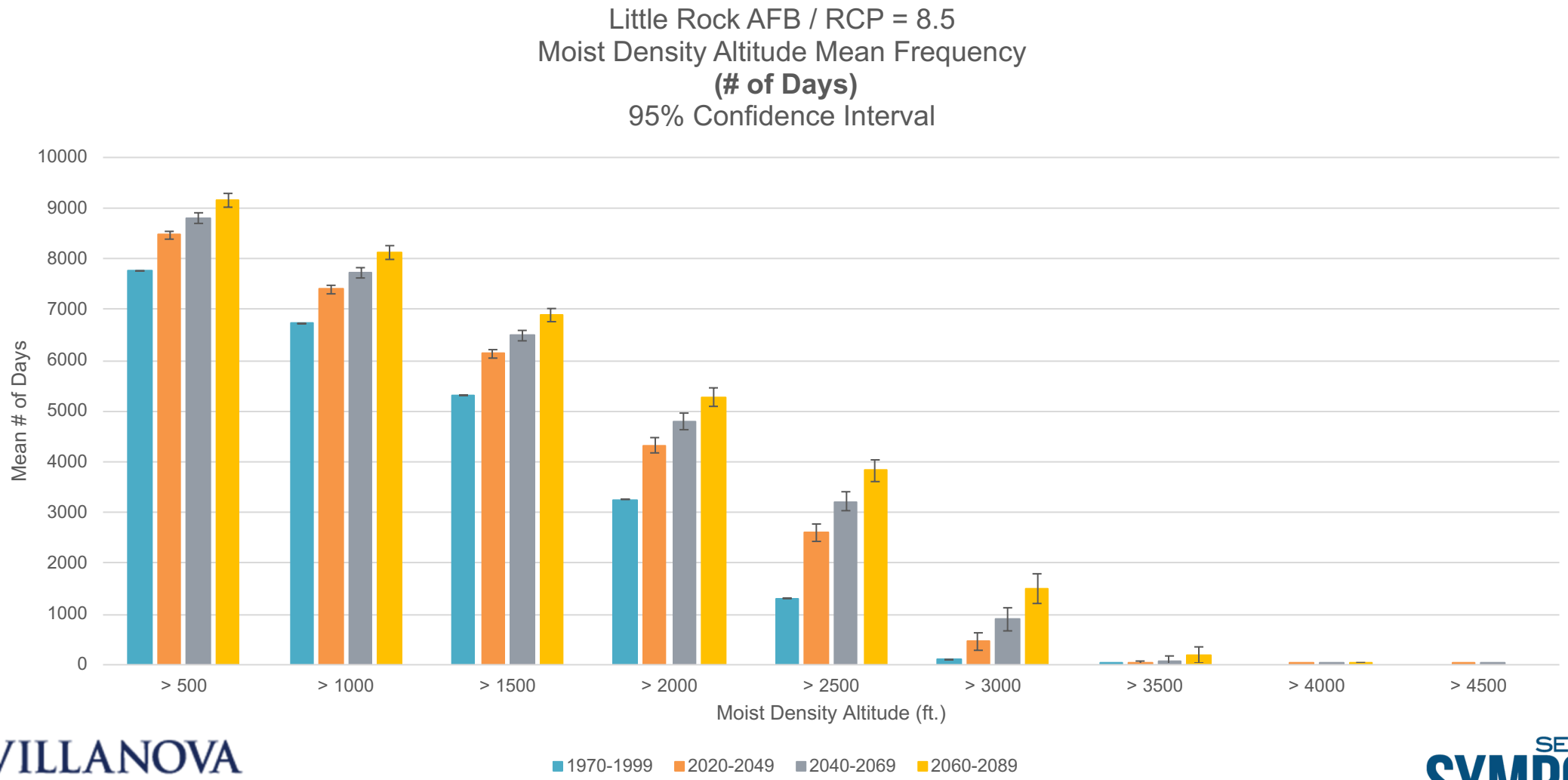
Density Altitude (DA) Performance Thresholds:

- Threshold 1: DA > 500 ft.
- Threshold 2: DA > 1000 ft.
- Threshold 3: DA > 1500 ft.
- Threshold 4: DA > 2000 ft.
- Threshold 5: DA > 2500 ft.
- Threshold 6: DA > 3000 ft.
- Threshold 7: DA > 3500 ft.
- Threshold 8: DA > 4000 ft.

Aircraft Specific Performance Thresholds (example):

- Threshold 1: 5,000 lbs. reduction in MTOW
- Threshold 2: Takeoff Distance > Runway
- Threshold 3: 10,000 lbs. reduction in MTOW
- Threshold 4: 15,000 lbs. reduction in MTOW
- Threshold 5: 20,000 lbs. reduction in MTOW

Density Altitude Performance Threshold



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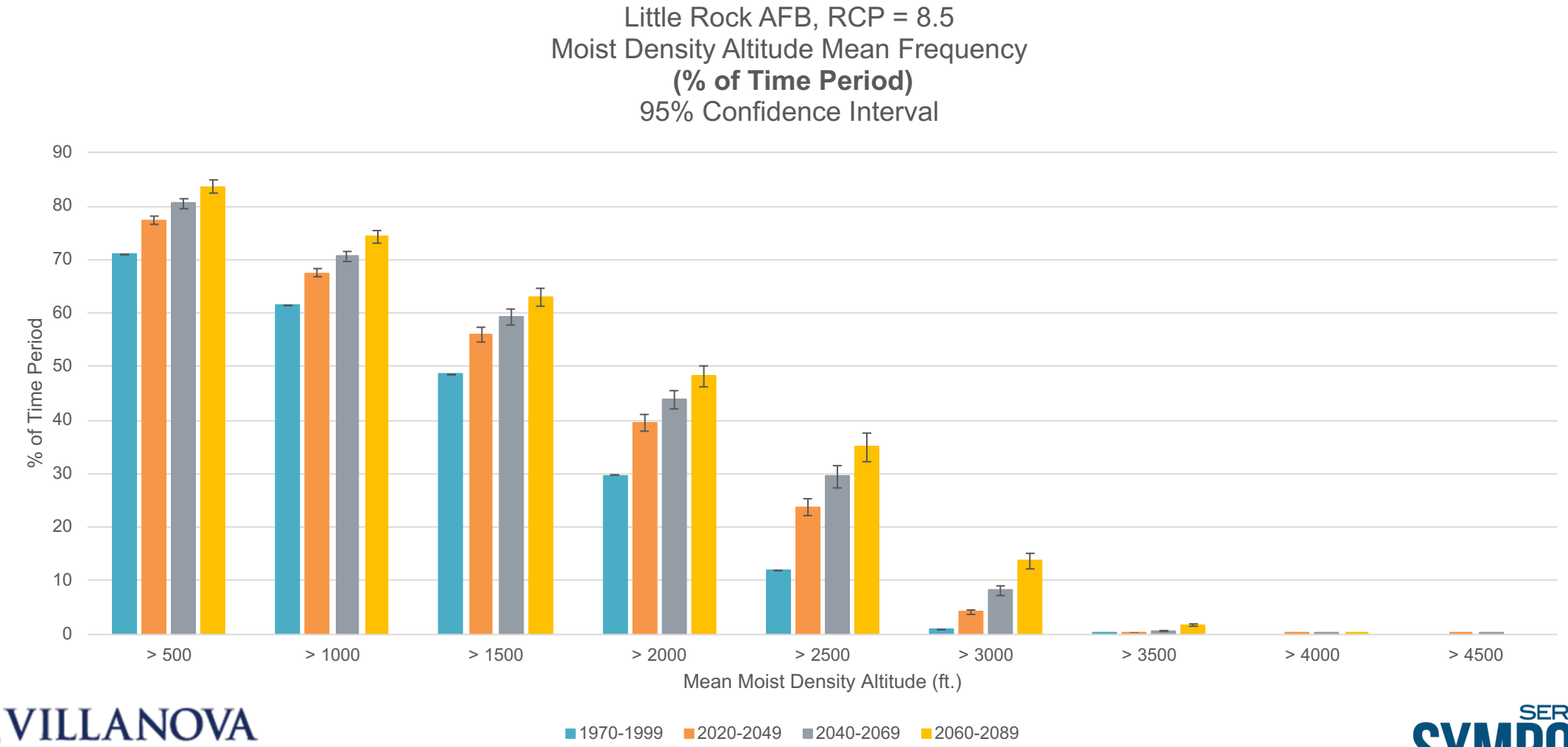
Density Altitude Performance Threshold



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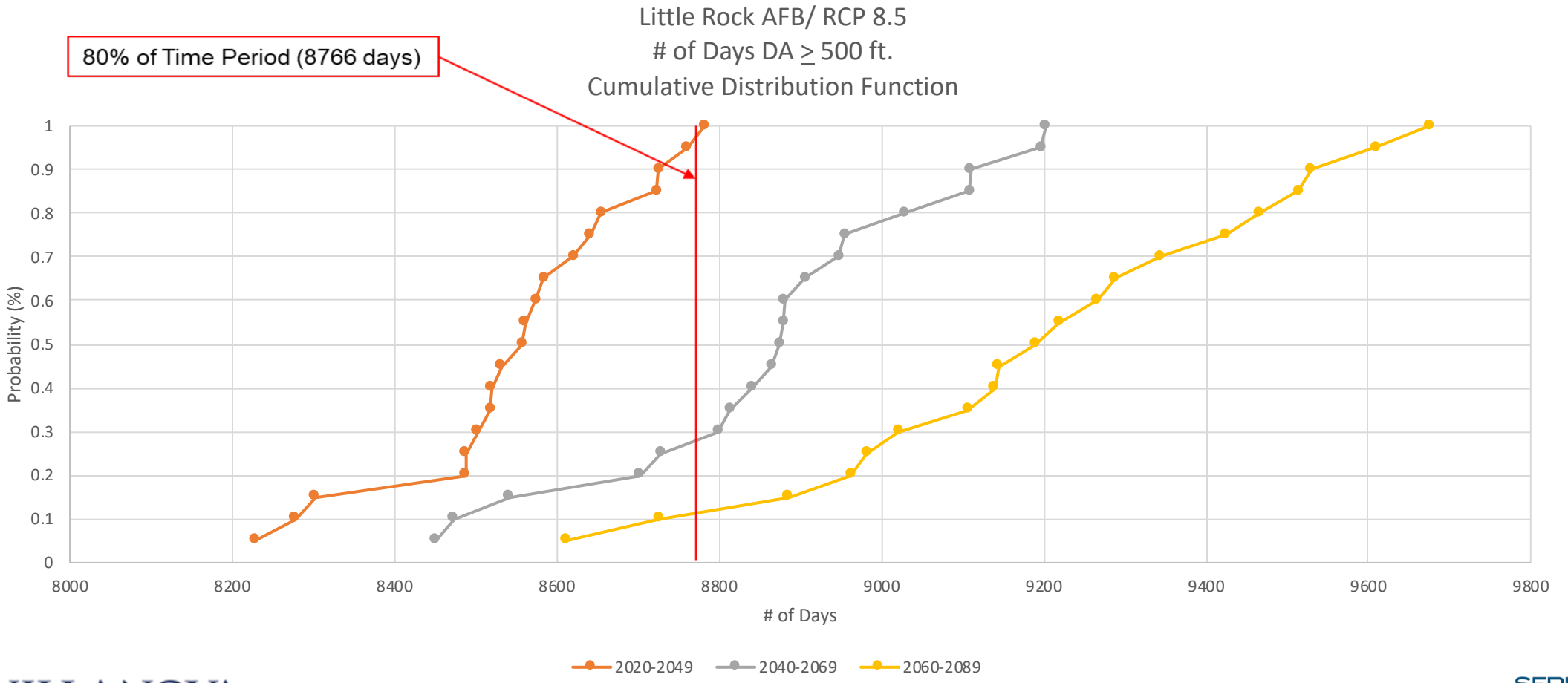
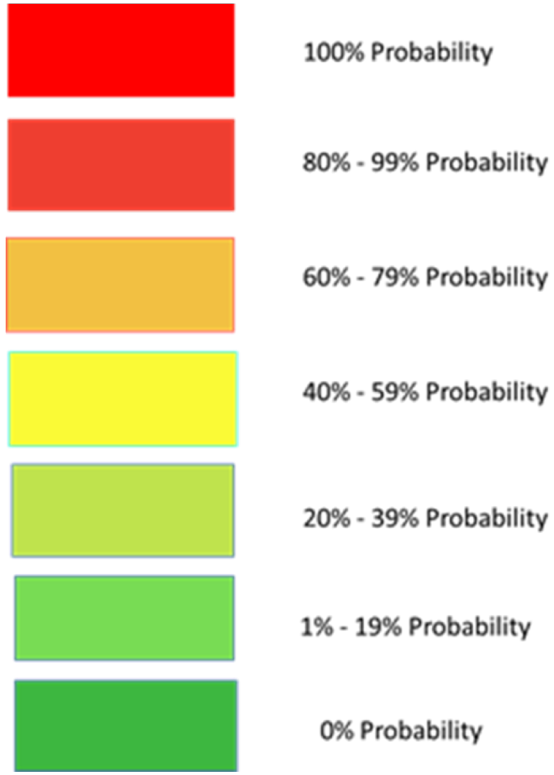
Density Altitude Probability



Correlate Thresholds to Probability of Surpassing These Thresholds

DATA captures:

- Multi-Model Ensemble GCMs
- Downscaled Bias Corrected
- Model Uncertainty
- Temp and Dew Point
- Location
- RCP
- Time Period
- Threshold



Density Altitude Threshold Risk Probability /Little Rock AFB, Observed **(1970-1999)**

% of Time Period > Threshold	Threshold 1: DA ≥ 500 ft.	Threshold 2: DA ≥ 1000 ft.	Threshold 3: DA ≥ 1500 ft.	Threshold 4: DA ≥ 2000 ft.	Threshold 5: DA ≥ 2500 ft.	Threshold 6: DA ≥ 3000 ft.	Threshold 7: DA ≥ 3500 ft.	Threshold 8 DA ≥ 4000 ft
1 day	100%	100%	100%	100%	100%	100%	100%	0%
10% (1096 days)						0%	0%	
20% (2191 days)					0%			
30% (3287 days)								
40% (4383 days)				0%				
50% (5479 days)								
60% (6574 days)			0%					
70% (7670 days)		0%						
80% (8766 days)	0%							
90% (9861 days)								
100% (10,957 days)								

Density Altitude Threshold Risk Probability /Little Rock AFB, RCP 8.5, (**2020-2049**)

% of Time Period > Threshold	Threshold 1: DA ≥ 500 ft.	Threshold 2: DA ≥ 1000 ft.	Threshold 3: DA ≥ 1500 ft.	Threshold 4: DA ≥ 2000 ft.	Threshold 5: DA ≥ 2500 ft.	Threshold 6: DA ≥ 3000 ft.	Threshold 7: DA ≥ 3500 ft.	Threshold 8 DA ≥ 4000 ft
1 day	100%	100%	100%	100%	100%	100%	100%	55%
10% (1096 days)						75%	0%	0%
20% (2191 days)						0%		
30% (3287 days)					75%			
40% (4383 days)					0%			
50% (5479 days)				0%				
60% (6574 days)			0%					
70% (7670 days)		0%						
80% (8766 days)	5%							
90% (9861 days)	0%							
100% (10,957 days)								

Density Altitude Threshold Risk Probability /Little Rock AFB, RCP 8.5, **(2040-2069)**

% of Time Period > Threshold	Threshold 1: DA ≥ 500 ft.	Threshold 2: DA ≥ 1000 ft.	Threshold 3: DA ≥ 1500 ft.	Threshold 4: DA ≥ 2000 ft.	Threshold 5: DA ≥ 2500 ft.	Threshold 6: DA ≥ 3000 ft.	Threshold 7: DA ≥ 3500 ft.	Threshold 8 DA ≥ 4000 ft
1 day	100%	100%	100%	100%	100%	100%	100%	90%
10% (1096 days)							0%	0%
20% (2191 days)						35%		
30% (3287 days)						0%		
40% (4383 days)					0%			
50% (5479 days)				45%				
60% (6574 days)			40%	0%				
70% (7670 days)		50%	0%					
80% (8766 days)	75%	0%						
90% (9861 days)	0%							
100% (10,957 days)								

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Density Altitude Threshold Risk Probability /Little Rock AFB, RCP 8.5, (**2060-2089**)

% of Time Period > Threshold	Threshold 1: DA ≥ 500 ft.	Threshold 2: DA ≥ 1000 ft.	Threshold 3: DA ≥ 1500 ft.	Threshold 4: DA ≥ 2000 ft.	Threshold 5: DA ≥ 2500 ft.	Threshold 6: DA ≥ 3000 ft.	Threshold 7: DA ≥ 3500 ft.	Threshold 8 DA ≥ 4000 ft
1 day	100%	100%	100%	100%	100%	100%	100%	100%
10% (1096 days)							40%	0%
20% (2191 days)						90%	0%	
30% (3287 days)						15%		
40% (4383 days)					55%	0%		
50% (5479 days)				80%	0%			
60% (6574 days)			90%	0%				
70% (7670 days)			0%					
80% (8766 days)	90%	0%						
90% (9861 days)	0%							
100% (10,957 days)								

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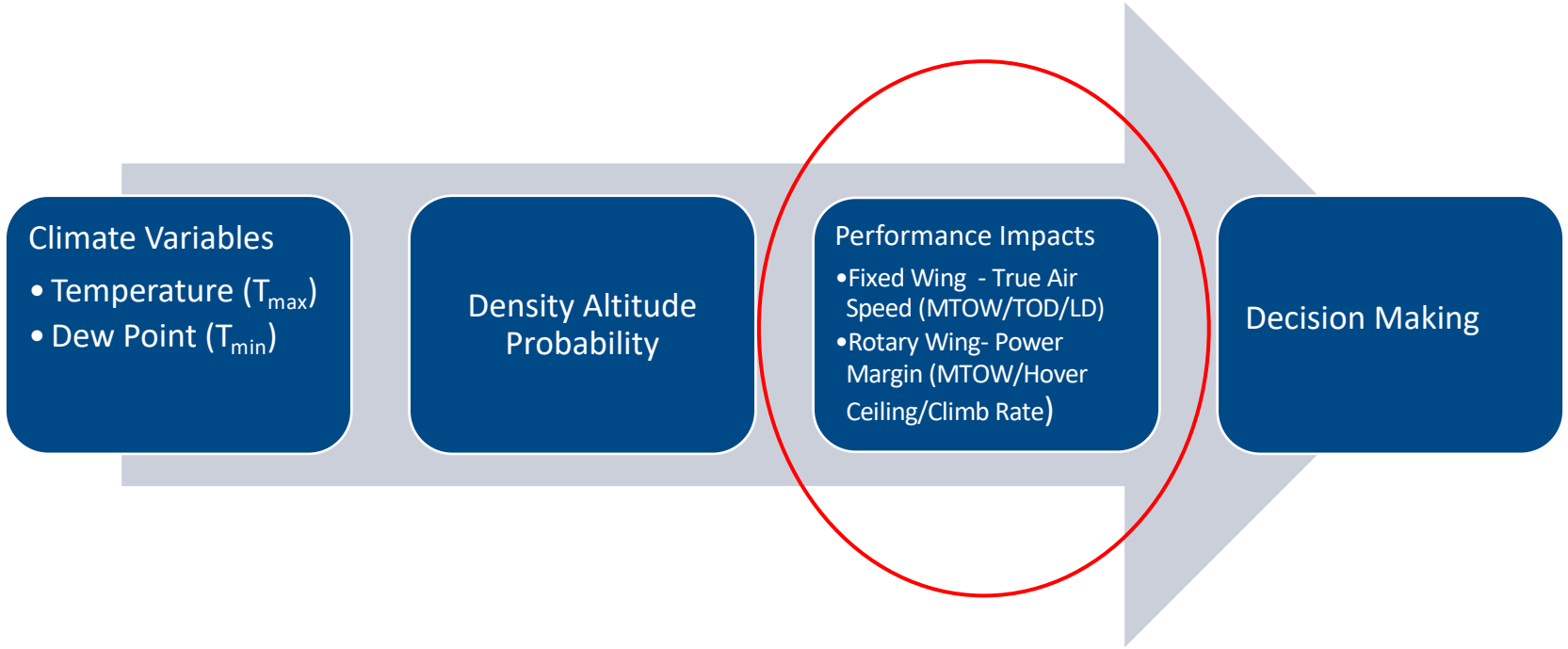
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Performance Impacts
•Fixed Wing - True Air Speed (MTOW/TOD/LD)
•Rotary Wing- Power Margin (MTOW/Hover Ceiling/Climb Rate)
Decision Making

Aircraft Specific Performance Thresholds

- **Fixed Wing**
  - Performance Impacts: Horsepower, Lift (True Air Speed)
    - Maximum Takeoff Weight (MTOW)
    - Takeoff Distance
    - Landing Distance
  - Performance Sources:
    - Aviation Experts
    - Flight Test Data - Technical Manual Performance Charts
    - General Aviation Rules of Thumb (for example purposes)
      - Maximum Takeoff Weight: 3.5% reduction in hp. for every 1000 ft. increase in DA
      - Takeoff Distance: 10% increase in takeoff distance for every 1000 ft. increase in DA
      - Landing Distance: 3.5% increase in landing distance for every 1000 ft. increase in DA

- **Rotary Wing**
  - Performance Impacts: Horsepower, Rotor Efficiency, Lift
    - Power Margin
    - Maximum Takeoff Weight (MTOW)
    - Hover Ceiling
    - Rate of Climb
  - Performance Sources:
    - Aviation Experts
    - Flight Test Data - Technical Manual Performance Charts
    - Power Margin Methodology (for example purposes)

Fixed Wing:
C-130J Example

Aircraft Characteristics:

- Max Takeoff Weight = 164,000 lbs.
- Max Payload = 42,000 lbs.
- Normal Payload = 34,000 lbs.
- Takeoff Distance (164,000 lbs.)
  - Max Effort = 3100 ft.
  - Normal = 5850 ft.
- Landing Distance (135,000 lbs.)
  - Max Effort = 1630 ft.
  - Normal = 3100 ft.

- Little Rock AFB Runways
  - Runway #1 (Assault Strip) = 3499 ft.
  - Runway #2 = 12,000 ft.

Performance Thresholds Estimates:

(Using General Aviation Rules of Thumb)

- Threshold 1
  - Max Takeoff Weight Reduced by 5,000 lbs.
- Threshold 2
  - Takeoff Distance Max Effort) > Assault Strip
- Threshold 3
  - Max Takeoff Weight Reduced by 10,000 lbs.
- Threshold 4.
  - Max Takeoff Weight Reduced by 15,000 lbs.
- Threshold 5
  - Max Takeoff Weight Reduced by 20,000 lbs.

Aircraft Specific Performance Threshold (C-130J) Risk Probability /Little Rock AFB, RCP 8.5, (**2020-2049)**

% of Time Period > Threshold	Threshold 1: (5,000 lbs. Reduction)	Threshold 2: (Takeoff ≥ Assault Strip)	Threshold 3: (10,000 lbs. Reduction)	Threshold 4: (15,000 lbs. Reduction)	Threshold 5: (20,000 lbs. Reduction)
1 day	100%	100%	100%	100%	100%
10% (1096 days)					0%
20% (2191 days)					
30% (3287 days)				75%	
40% (4383 days)				0%	
50% (5479 days)			95%		
60% (6574 days)		95%	0%		
70% (7670 days)		0%			
80% (8766 days)	0%0				
90% (9861 days)					
100% (10,957 days)					

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Aircraft Specific Performance Threshold (C-130J) Risk Probability /Little Rock AFB, RCP 8.5, (**2040-2069)**

% of Time Period > Threshold	Threshold 1: (5,000 lbs. Reduction)	Threshold 2: (Takeoff ≥ Assault Strip)	Threshold 3: (10,000 lbs. Reduction)	Threshold 4: (15,000 lbs. Reduction)	Threshold 5: (20,000 lbs. Reduction)
1 day	100%	100%	100%	100%	100%
10% (1096 days)					10%
20% (2191 days)					0%
30% (3287 days)					
40% (4383 days)				0%	
50% (5479 days)					
60% (6574 days)			0%		
70% (7670 days)		0%			
80% (8766 days)	10%				
90% (9861 days)	0%				
100% (10,957 days)					

Aircraft Specific Performance Threshold (C-130J) Risk Probability /Little Rock AFB, RCP 8.5, (**2060-2089**)

% of Time Period > Threshold	Threshold 1: (5,000 lbs. Reduction)	Threshold 2: (Takeoff ≥ Assault Strip)	Threshold 3: (10,000 lbs. Reduction)	Threshold 4: (15,000 lbs. Reduction)	Threshold 5: (20,000 lbs. Reduction)
1 day	100%	100%	100%	100%	100%
10% (1096 days)					55%
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30% (3287 days)					0%
40% (4383 days)				55%	
50% (5479 days)				0%	
60% (6574 days)			50%		
70% (7670 days)		40%	0%		
80% (8766 days)	60%	0%			
90% (9861 days)	0%				
100% (10,957 days)					

Rotary Wing
UH-60L Example

Aircraft Characteristics

- T700-GE-701D Engine, 100% RPM
  - 2.5 minute hover (4000 hp.)
  - 10 minute hover (3988 hp.)
  - 30 minute hover (3804 hp.)
- Maximum Gross Weight = 22,000 lbs.
- Primary Mission Gross Weight = 17,706 lbs.

Power Margin Methodology: (Power Have – Power Need)

- Power HAVE (decreases)
  - (3.5% loss for every 1000 ft. increase in DA)
- Power NEED (increases)
  - Froudes' Momentum Theory:

$$P_{id} = W \cdot v_i = W \cdot \sqrt{(W/2\rho A)}$$

- Calculate % difference between time periods

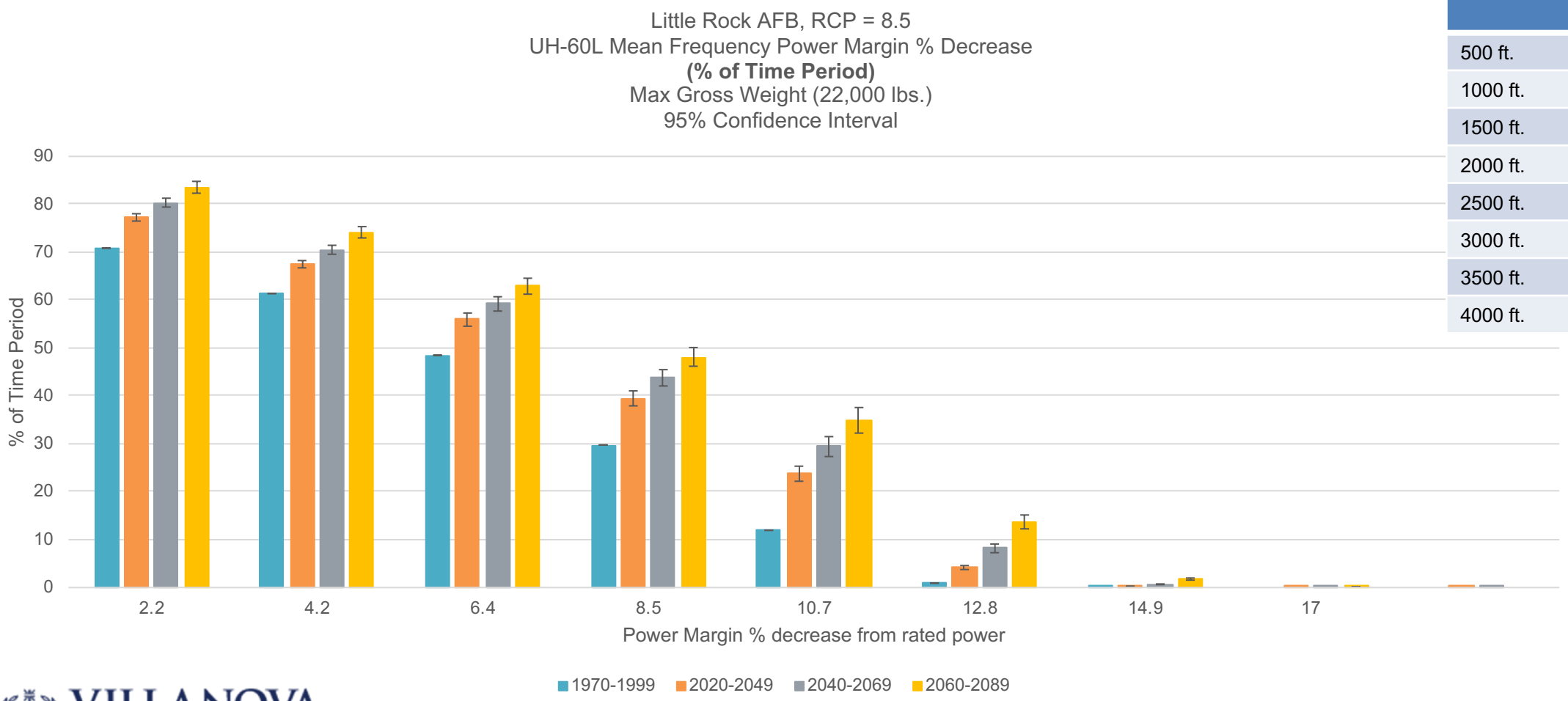
Ex: (1970-1999) & (2020-2049)

Performance Threshold = Power Margin % Decrease from Sea Level (rated power)
UH-60L Example

Density Altitude Threshold	Aircraft Performance Threshold (Power Margin % Decrease) (Max Gross Weight 22,000 lbs.)	Aircraft Performance Threshold (Power Margin % Decrease) (Primary Mission Gross Weight (17,706 lbs.)
> 500 ft.	2.2	2.1
> 1000 ft.	4.2	4
> 1500 ft.	6.4	6.1
> 2000 ft.	8.5	8.1
> 2500 ft.	10.7	10.2
> 3000 ft.	12.8	12.2
> 3500 ft.	14.9	14.2
> 4000 ft.	17	16.2

Power Margin % decrease remains constant for engine power variations because comparing to rated power for corresponding engine power

Aircraft Specific Performance Impact Thresholds
UH-60L Example



DA Threshold	PM % decrease
500 ft.	2.2
1000 ft.	4.2
1500 ft.	6.4
2000 ft.	8.5
2500 ft.	10.7
3000 ft.	12.8
3500 ft.	14.9
4000 ft.	17.0

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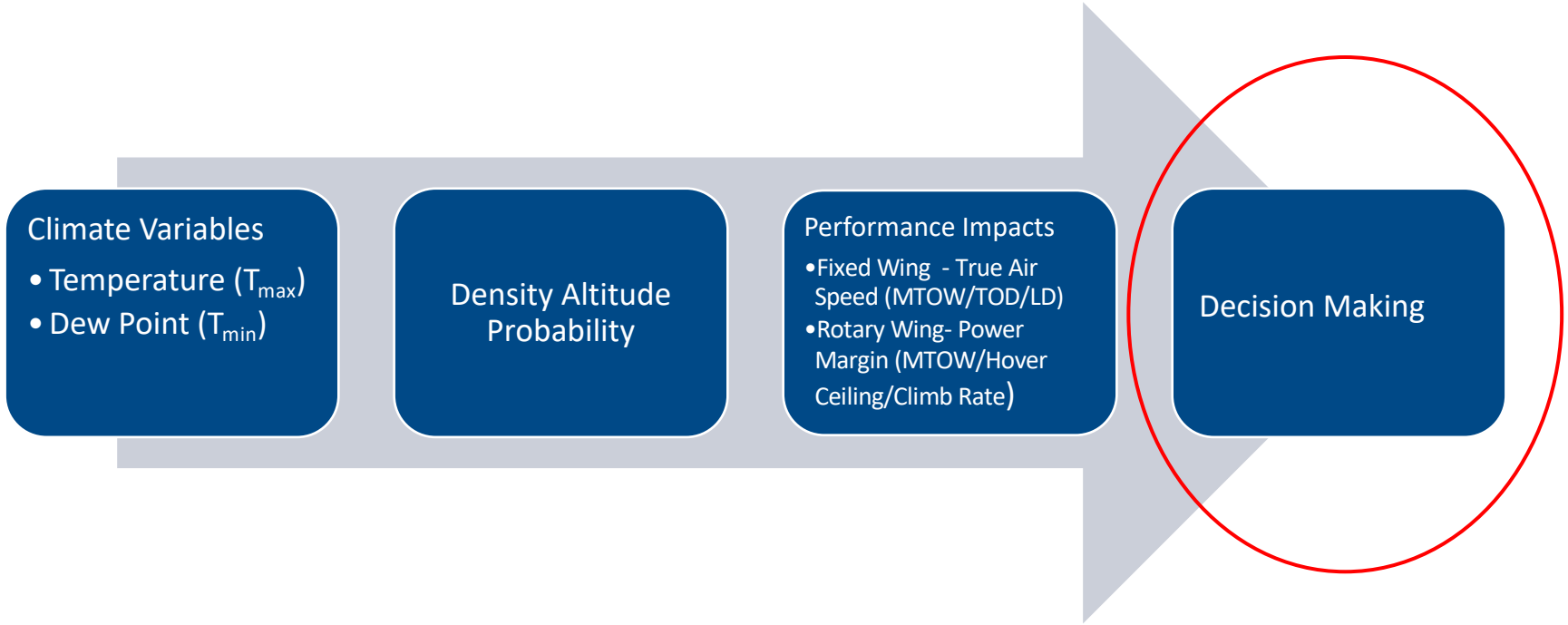
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Decision Making

Incorporate Sustainable Engineering Impacts

STEEP: a holistic assessment of rising temperatures and aircraft performance impacts

- Identify measurable criteria to reflect stakeholder values in each of the following areas:
  - **S**ocial - Installation personnel
    - Demographics, lifestyles, social and cultural values
  - **T**echnical - Aircraft industry, DoD Acquisition
    - Technical impacts to mission - transport, energy, research & development.
  - **E**nvironmental - Environmental protection agencies
    - Ecosystem factors – water, soil, food, energy
  - **E**conomic – Dept. of Defense Acquisition
    - Budgets, personnel, training
  - **P**olitical – Dept. of Defense policies
    - Shifting political landscape

Preliminary STEEP Objectives / Criteria

- **Social** - Maximize Quality of Life for Installation Personnel
  - Maximize Crew Safety
  - Minimize Personnel Load
  - Minimize Budget Cuts to Personnel Levels/Training
- **Technical** - Maximize Aircraft Performance
  - Identify and incorporate requirements for reduced Power Margin
  - Identify and incorporate requirements for increased True Air Speed
  - Identify and incorporate requirements for payload restrictions
- **Environmental** - Minimize impact to local environment
  - Minimize precipitation runoff
  - Minimize biodiversity disturbance
  - Minimize carbon emissions
- **Economic** - Minimize Operational Costs
  - Minimize aircraft fuel costs
  - Minimize infrastructure costs
- **Political** - Maximize alignment with Federal Policy
  - Identify and incorporate impacts to state/region
  - Identify increased risk exposure to troops
  - Identify impacts of increased operating budget

Vulnerability Assessment Model

1. Establish Confidence Factor (Model Agreement)
    - High (100% model agreement)
    - Medium (50% - 95% model agreement)
    - Low (5% - 45% model agreement)
2. Determine Risk Probability Score for each threshold
    - High = 1.0 ($\geq$ 80% occurrence)
    - Med = 0.667 (50% – 75% occurrence)
    - Low = 0.333 (< 50% occurrence)
    - Not Applicable = 0.0 (Not one day)
3. Define Level of Relevance Score for each criteria
    - Essential = 3.0 (ex. mission is terminated)
    - Critical = 1.0 (ex. additional sorties required)
    - Routine = 0.33 (ex. fuel taken off)
    - No importance = 0.0 (no impact)
4. Weighting (%) = [(Level of Relevance Score / $\sum$Level of Relevance Scores)] x 100
5. Threshold (T) Vulnerability Score = (Risk Probability Score) x (Weighting)
6. Overall Vulnerability Score = Σ^{n}_{1} Threshold Vulnerability Score

Multiple ways to “package” the Vulnerability Assessment Model

- Installations
- Time Period (Year/Month)
- Emissions Scenarios
- Aircrafts
- Aircraft Impacts
- STEEP factors
- Confidence Factor

TECHNICAL - Compare Between DA Thresholds
One Installation, One Emissions Scenario, One Time Period, MTOW for multiple aircraft
Little Rock AFB / RCP 8.5 / 2060-2089 / C-130J + other aircraft …

- Confidence Factor: High (100% model agreement)
- Thresholds: DA: ≥ 1000 ft., ≥ 2000 ft., ≥ 3000 ft.
- Risk Probability Score:
  High: ≥ 80% occurrence (1.0)
  Medium: 50% - 79% occurrence (0.667)
  Low: < 50% occurrence (0.333)
  N/A: Not one day (0.00)
- Relevance Score: Maximum Takeoff Weight (MTOW) for C-130J
  - Essential = 3.0 (C-130J MTOW reduced by > 20,000 lbs.)
  - Critical = 1.0 (C-130J MTOW reduced by > 10,000 lbs.)
  - Routine = 0.33 (C-130J MTOW reduced by > 5,000 lbs.)
  - No importance = 0 (C-130J MTOW not impacted)

Threshold C-130J MTOW	DA ≥ 1000 ft. Little Rock AFB	DA ≥ 2000 ft. Little Rock AFB	DA ≥ 3000 ft. Little Rock AFB
Risk Probability Score	High: 1.0	Med: 0.667	Low: 0.333
Relevance Score	Routine (0.33)	Critical (1.0)	Essential (3.0)
Weighting	0.33/4.33 = 8%	1.0/4.33 = 23%	3.0/4.33 = 69%
Threshold Vulnerability Score	(1.0)(8) = 8	(.667)(23) = 15	(O.333)(69) =23

Threshold Vulnerability Scores allow comparison between DA Thresholds

Overall Vulnerability Score: Little Rock AFB: C130J MTOW :	46

+

Other Aircraft using Little Rock AFB

Overall Vulnerability Score allows comparison to other installations

Example

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TECHNICAL
Multiple Installations, One Emissions Scenario, One Time Period, Specific Aircraft Impact
Little Rock, Davis Monthan, Hurlburt / RCP 8.5 / 2060-2089 / C-130J 5000 lb. reduction

- Confidence Factor: Low (5% – 45% model agreement)
- Threshold = C130J 5000 lb. payload reduction
- Risk Probability Score:
  High: ≥ 80% occurrence (1.0)
  Medium: 50% - 79% occurrence (0.667)
  Low: < 50% occurrence (0.333)
  N/A: Not one day (0.00)
- Relevance Score: C-130J 5000 lb. reduction
  - Essential = 3.0 (Mission is scrapped.)
  - Critical = 1.0 (Additional aircraft added)
  - Routine = 0.33 (Payload/Fuel reduced)
  - No importance = 0 (no impact)

In this example, the relevance score stays constant

Threshold	5000 lb. reduction Little Rock AFB	5000 lb. reduction Davis Monthan AFB	5000 lb. reduction Hurlburt Field
Risk Probability Score	Med: 0.667	High: 1.0	Low: 0.333
Relevance Score	Routine (0.33)	Routine (0.33)	Routine (0.33)
Weighting	0.33/1.0 = 33%	0.33/1.0 = 33%	0.33/1.0 = 33%
Threshold Vulnerability Score	(0.667)(33) = 22	(1.0)(33) = 33	(0.333)(33) =11

Threshold Vulnerability Scores allow comparison between installations

Overall Vulnerability Score: C130J: 5000 lb. payload reduction :	66

Overall Vulnerability Score allows comparison between various aircraft

Example

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ENVIRONMENTAL (Biodiversity Disturbance due to Runway Expansion): Multiple Installations, One Emissions Scenario, One Time Period, One Aircraft Little Rock, Davis Monthan, Hurlburt / RCP 8.5 / 2060-2089 / C-130J

- Confidence Factor: High (100% model agreement)
- Threshold: C-130J Takeoff Distance increases by > 1000 ft.
- Risk Probability Score:
  High: ≥ 80% occurrence (1.0)
  Medium: 50% - 79% occurrence (0.667)
  Low: < 50% occurrence (0.333)
  N/A: Not one day (0.00)
- Relevance Score: Runway extension required
  - Essential = 3.0 (Wetlands are 100% removed)
  - Critical = 1.0 (Wetlands are disturbed > 50%)
  - Routine = 0.33 (Wetlands are disturbed < 50%)
  - No importance = 0 (No extension required)

Threshold	TOD increase > 1000 ft. Little Rock AFB	TOD increase > 1000 ft. Davis Monthan AFB	TOD increase > 1000 ft. Hurlburt Field
Risk Probability Score	High: 1.0	Med: 0.667	Low: 0.333
Relevance Score	Essential (3.0)	Critical (1.0)	No importance (0.0)
Weighting	3.0/4.0 = 75%	1.0/4.0 = 25%	0.0/4.0 = 0%
Threshold Vulnerability Score	(1.0)(75) = 75	(0.667)(25) =17	(0.333)(0) = 0

Threshold Vulnerability Scores allow comparison between installations

Roll-up Vulnerability Score: ENVIRONMENTAL: C-130J 2000 ft. Runway Extension:	92

+ Other Aircraft

Overall Vulnerability Score allows comparison between various aircraft

Example

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Recommendations

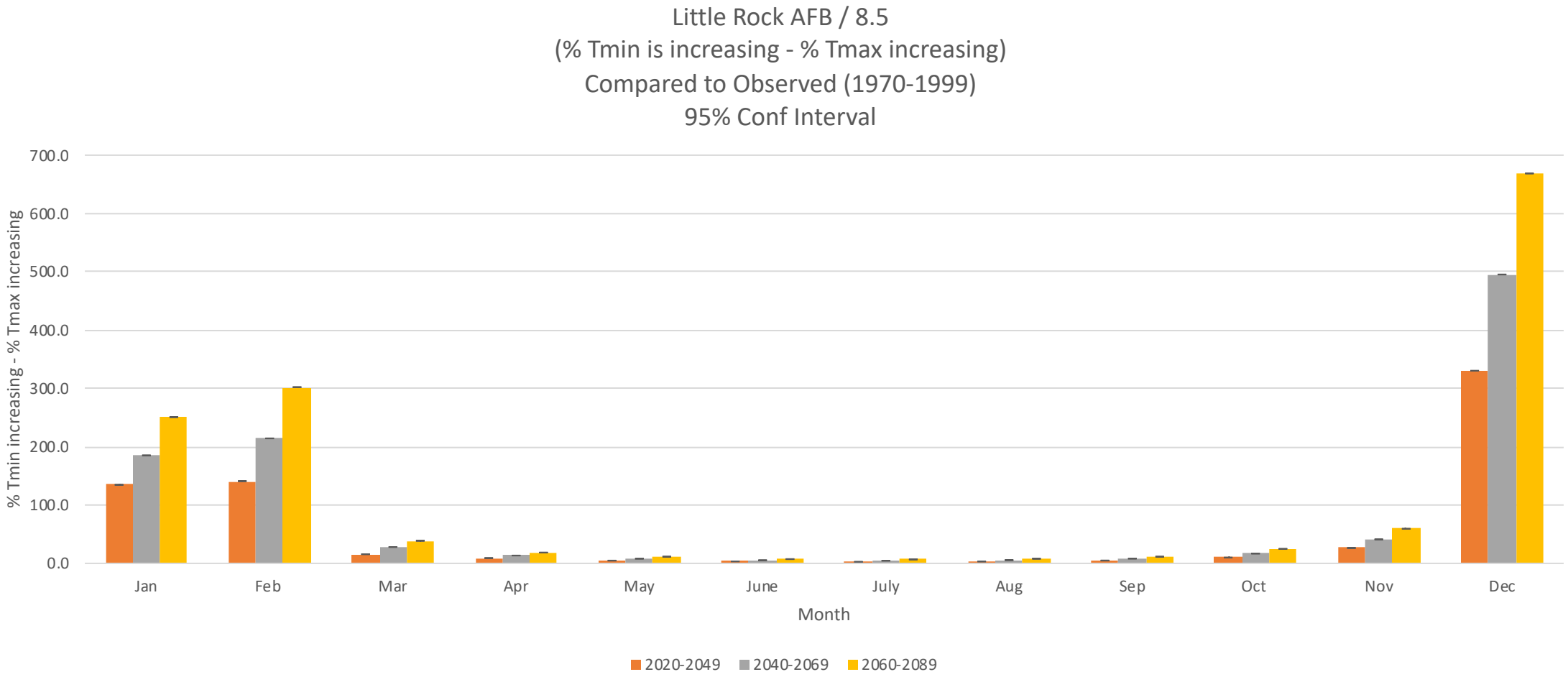
- Transition research framework to application
  - Develop template overlay
  - Expand to other installations
- Integrate stakeholder input to refine STEEP criteria
- Integrate into Joint Capabilities Integration & Development System (JCIDS) process
  - Vulnerability Score dialogue needs to start here
- Integrate into Defense Acquisitions System
  - Translate into key performance parameters

Thank You!

Questions?

- Back ups

T_{min} increasing at higher rate than T_{max}



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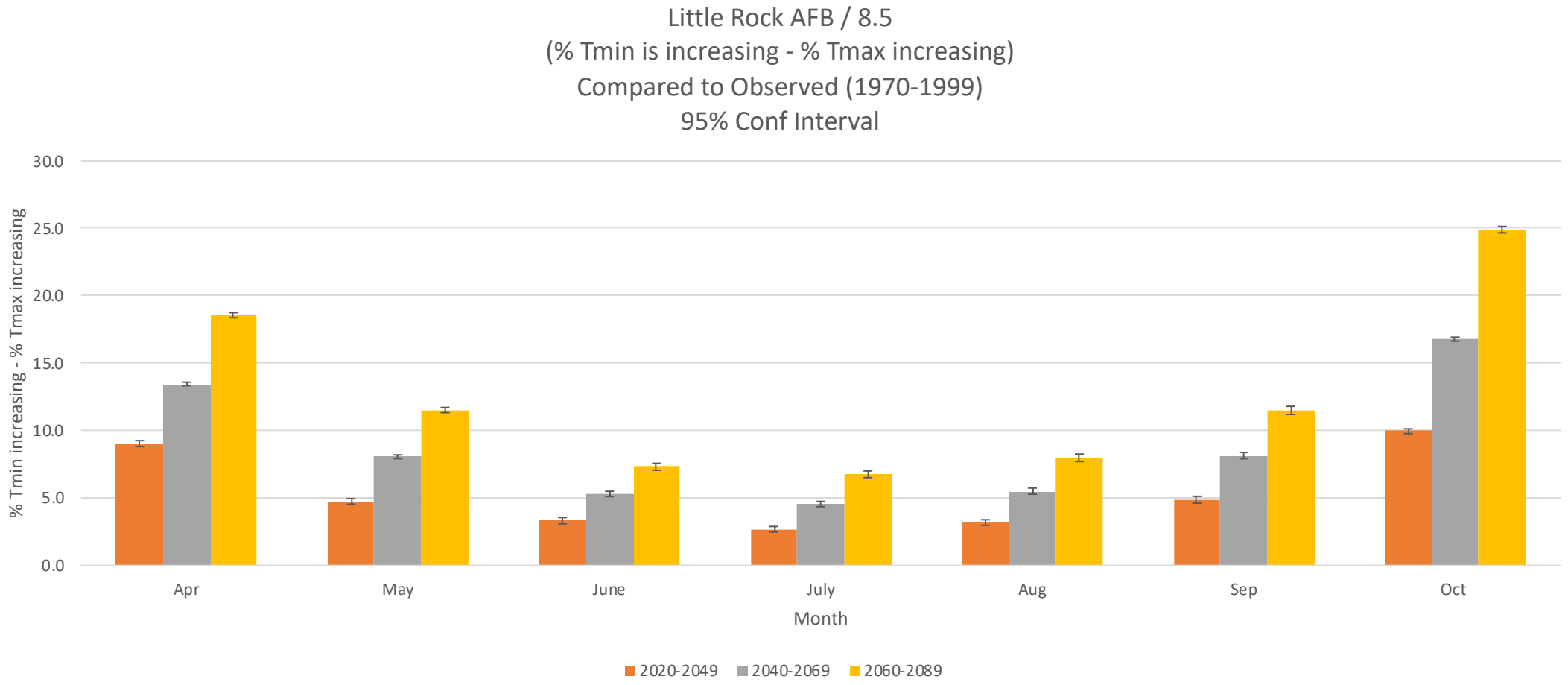
T_{min} increasing at higher rate than T_{max}



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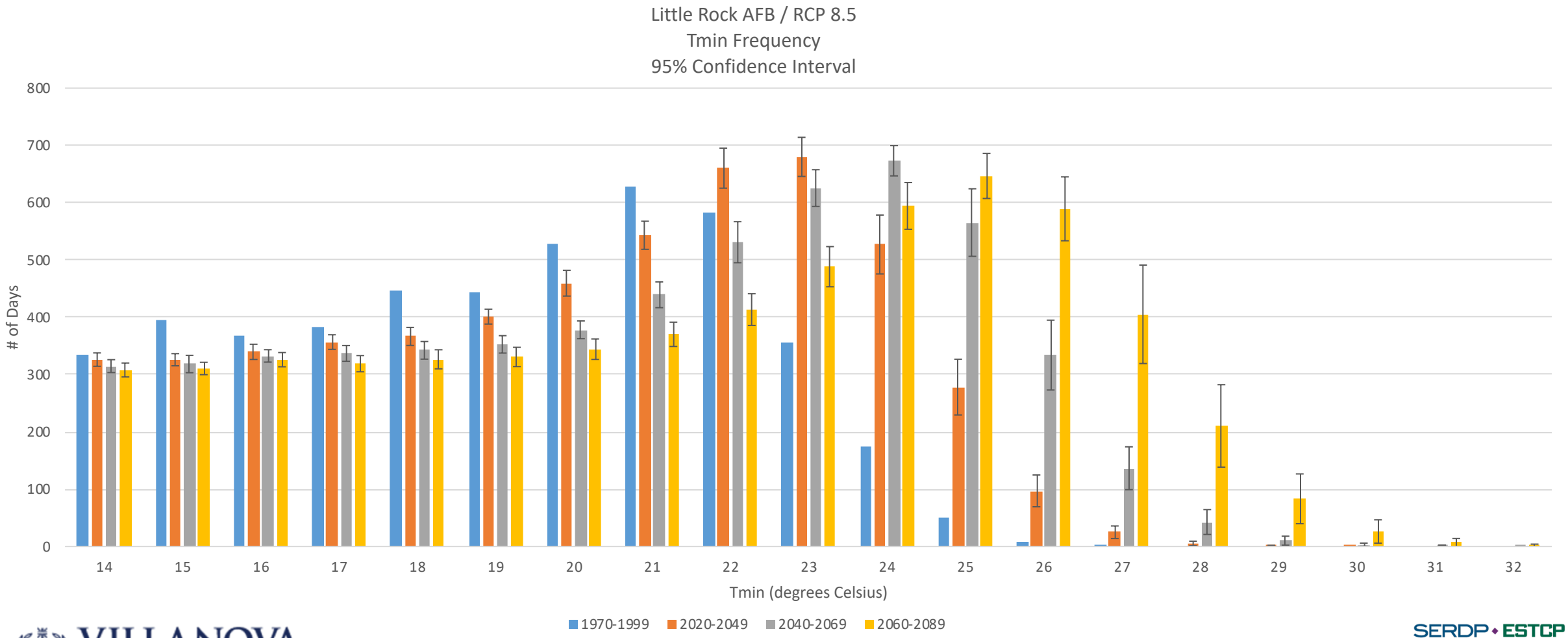
	Most Frequent T_{min} (°C)	Most Frequent T_{max} (°C)
1970-1999	21	29
2020-2049	23	34
2040-2069	24	35
2060-2089	25	36

	Highest Frequency T_{min} at T_{max} = 29C	Highest Frequency T_{min} at T_{max} = 34C	Highest Frequency T_{min} at T_{max} = 35C	Highest Frequency T_{min} at T_{max} = 36C
1970-1999	19C	22C	22C	22C
2020-2049	18C	22C	23C	23C
2040-2069	18C	23C	23C	24C
2060-2089	17C	23C	24C	24C



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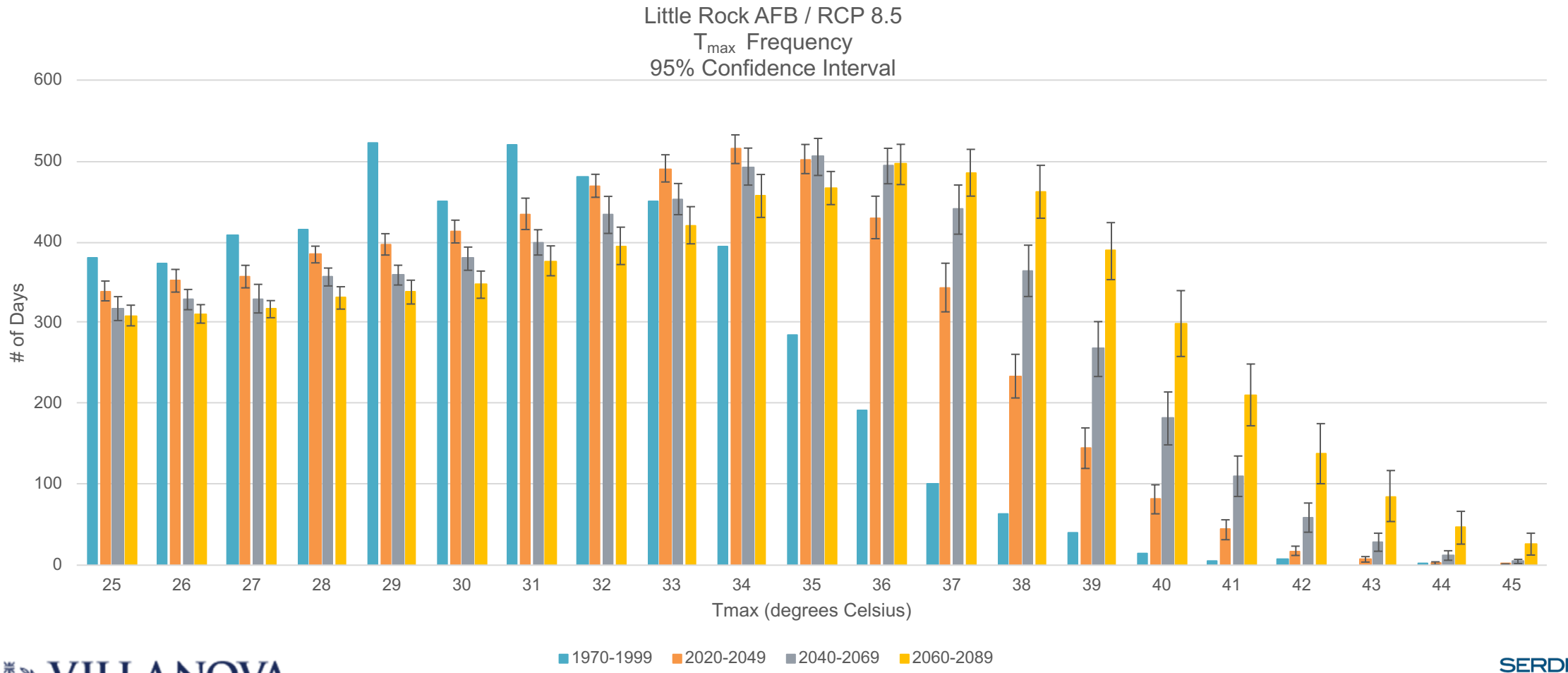

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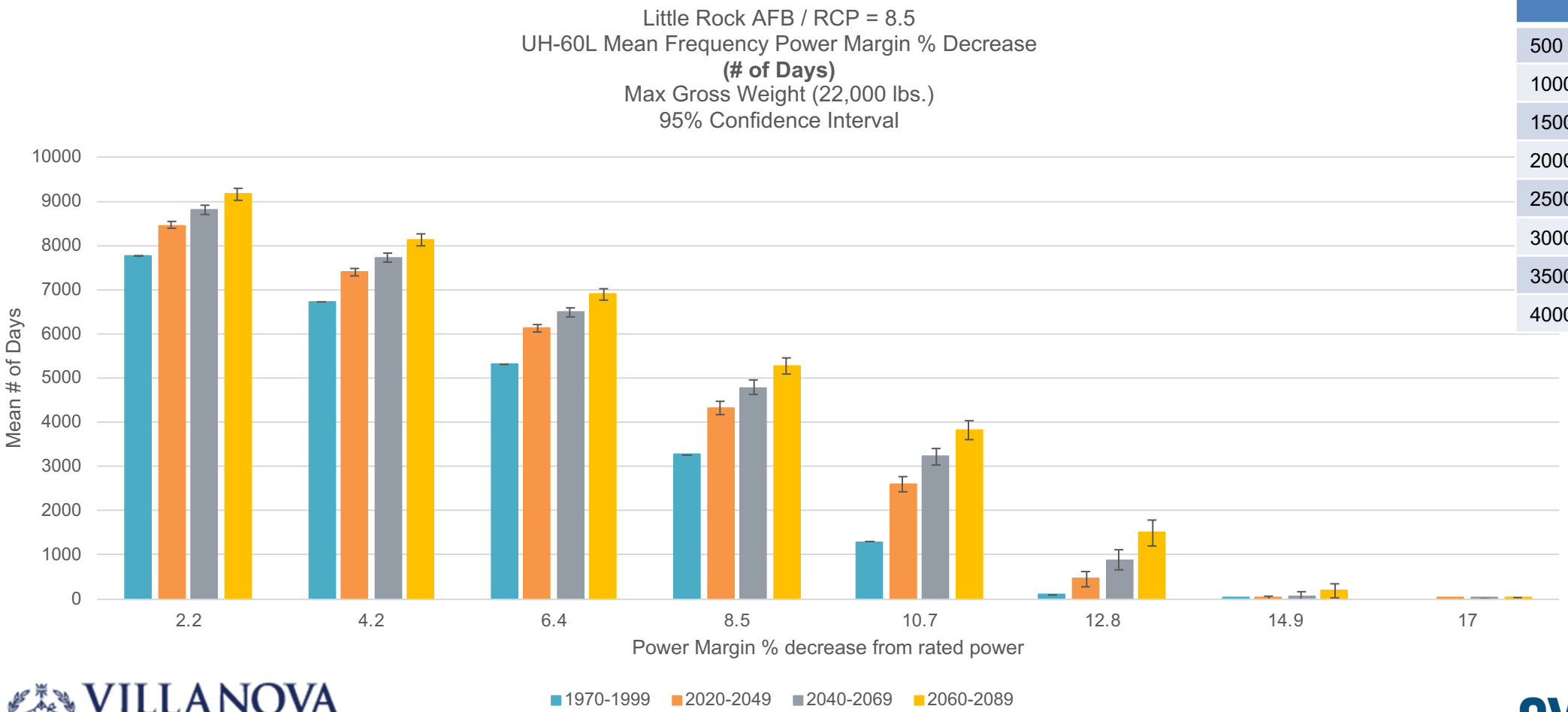
Aircraft Specific Performance Impact Thresholds
UH-60L Example



DA Threshold	PM % decrease
500 ft.	2.2
1000 ft.	4.2
1500 ft.	6.4
2000 ft.	8.5
2500 ft.	10.7
3000 ft.	12.8
3500 ft.	14.9
4000 ft.	17.0