KOREA 2021

DISCOVERY SUMMIT

EXPLORING DATA
INSPIRING INNOVATION

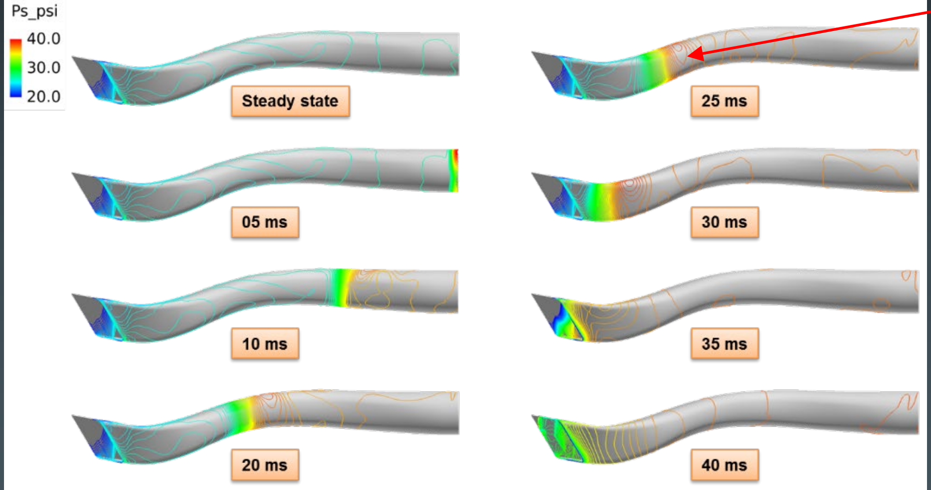
전투기 흡입구 해머쇼크 설계압력에 대한 확률론적 접근법 (Probabilistic Approach for Fighter Inlet Hammershock Design Pressure)

Nov. 2021

한국항공우주산업㈜ 배효길 수석

Intro

- **What is hammershock?**
  - Hammershock is the design bursting pressures for inlet duct result from an engine surge or stall which can be described as a sudden reduction in flow
  - This sudden reduction in flow creates a strong shock wave, referred to as a hammershock, which moves upstream



Shock moves forward

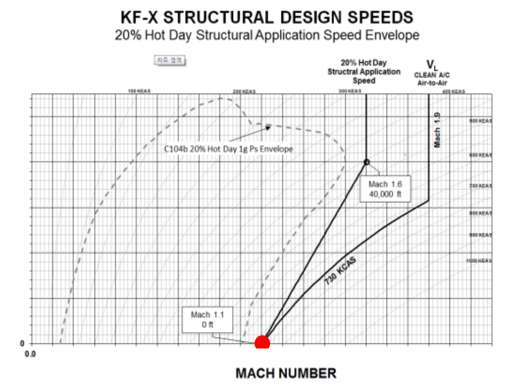
Intro

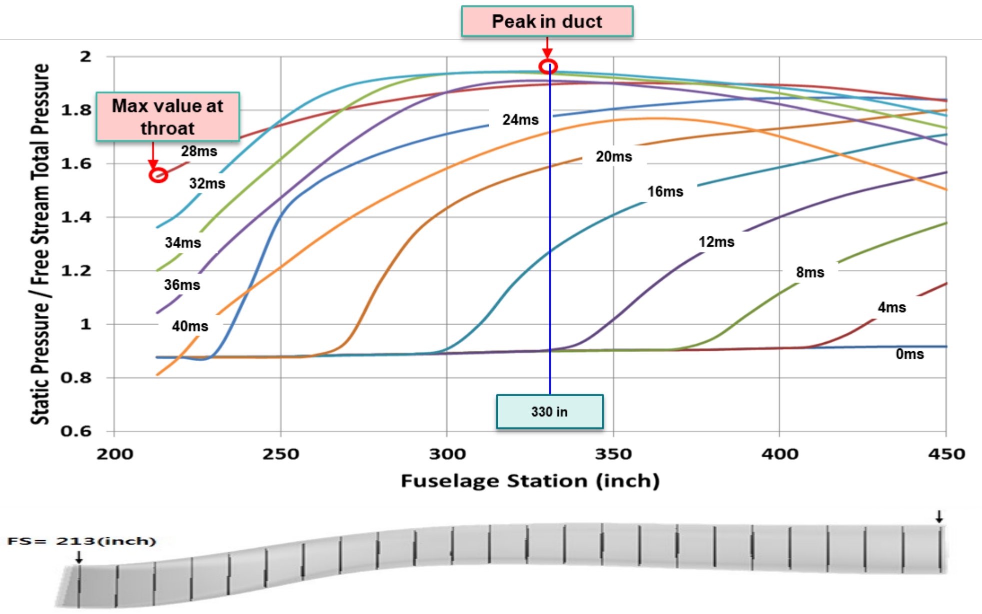
- **Design Objective**
  - Try to appropriate inlet hammershock pressure
  - Then reduce the weight of inlet duct structure
  - Therefore reduce the operation cost during aircraft service life

- **Methodology**
  - Deterministic approach
    - Analyze the inlet hammershock at the worst conditions ; max speed, cold day, max hammershock peak
    - However, the probability of max hammershock happening during service life is very low
  - Probabilistic approach
    - Consider input parameters as random variables with mean and variance
    - Conduct Monte Carlo Simulation (MCS) to generate inlet hammershock output as random output

Inlet Duct Pressure by Deterministic Approach

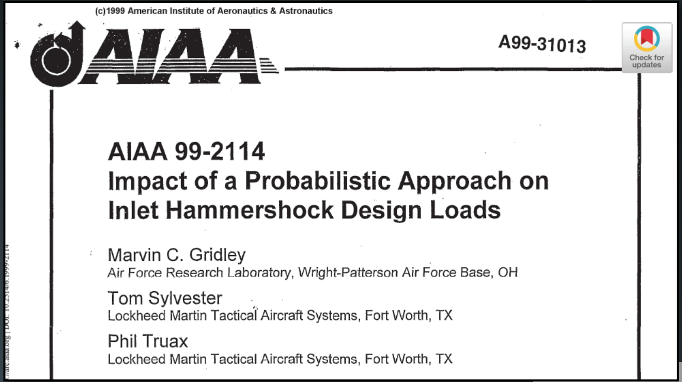
- **Inlet duct pressure analyzed at extreme condition**
  - Extreme condition: M1.1, Alt=SL, 20% cold day
  - At throat, max ultimate pressure ΔP_ult = xx psid at 28 ms (milli-sec)
  - In duct, max ultimate pressure ΔP_ult = xx psid at 32 ms





Previous Paper : Probabilistic Work Flow

- Generate PDF of ΔPult & Search for ΔPult for design



A99-31013

AIAA 99-2114
Impact of a Probabilistic Approach on Inlet Hammershock Design Loads

Marvin C. Gridley
Air Force Research Laboratory, Wright-Patterson Air Force Base, OH
Tom Sylvester
Lockheed Martin Tactical Aircraft Systems, Fort Worth, TX
Phil Truax
Lockheed Martin Tactical Aircraft Systems, Fort Worth, TX

$$\triangle P_{ult} = 1.5 \times (P_{hs} - P_0)$$

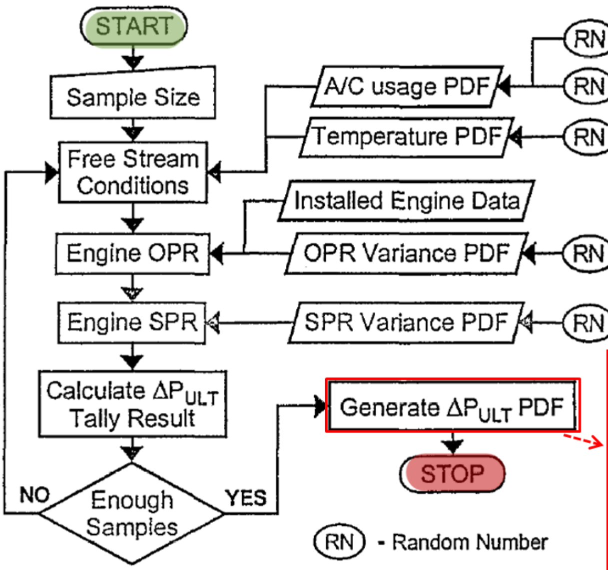


Figure 1. ΔP_{ult} Cumulative Probability Distribution Calculation Procedure

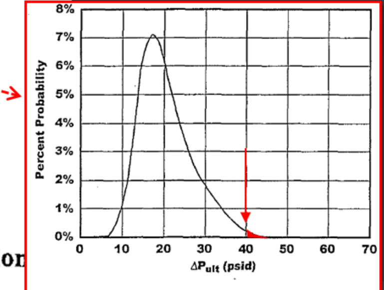


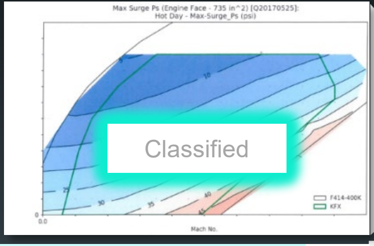
Figure 8. ΔP_{ult} Probability Distribution

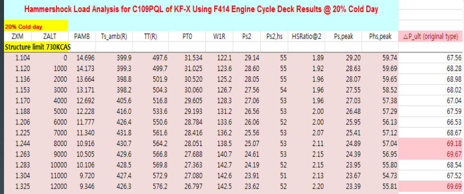
※ OPR : Operating Pressure Ratio
SPR : Stall Pressure Ratio
PDF : Probability Density Function

※ MCS : Monte Carlo Simulation

Proposed Probabilistic Work Flow

- **Search for Design Pressure ΔPult**

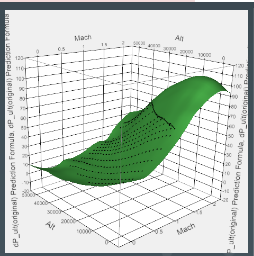




Hammershock Load Analysis for C109PQL of KF-X Using F414 Engine Cycle Deck Results @ 20% Cold Day

20% Cold day

ZXM	ZALT	PAMB	Ts_amb(R)	TT(R)	PT0	W1R	Ps2	Ps2,hs	HSRatio@2	Ps,peak	Phs,peak	△P_ult (original type)
Structure limit 730KCAS												
1.104	0	14.696	399.9	497.6	31.534	122.1	29.14	55	1.89	29.20	59.74	67.56
1.120	1000	14.173	399.3	499.7	31.025	123.6	28.60	55	1.92	28.63	59.69	68.28
1.136	2000	13.664	398.8	501.9	30.520	125.2	28.05	55	1.96	28.07	59.65	68.98
1.153	3000	13.171	398.2	504.3	30.060	126.7	27.56	54	1.96	27.55	58.52	68.02
1.170	4000	12.692	405.6	516.8	29.605	128.3	27.06	53	1.96	27.03	57.38	67.04
1.188	5000	12.228	416.0	533.6	29.193	131.2	26.56	53	2.00	26.48	57.29	67.59
1.206	6000	11.777	426.4	550.6	28.784	133.6	26.06	52	2.00	25.95	56.13	66.53
1.225	7000	11.340	431.8	561.6	28.416	136.2	25.56	53	2.07	25.41	57.12	68.67
1.244	8000	10.916	430.7	564.2	28.051	138.5	25.07	53	2.11	24.89	57.04	69.18
1.263	9000	10.505	429.6	566.8	27.688	140.7	24.61	53	2.15	24.39	56.95	69.67
1.283	10000	10.106	428.5	569.8	27.363	142.7	24.19	52	2.15	23.95	55.80	68.54
1.304	11000	9.720	427.4	572.9	27.080	142.6	23.91	51	2.13	23.67	54.73	67.52
1.325	12000	9.346	426.3	576.2	26.797	142.5	23.62	52	2.20	23.39	55.81	69.69
1.347	13000	8.984	425.2	579.7	26.551	142.2	23.38	50	2.14	23.15	53.67	67.03



START

① P_{hs} Data at Engine Face from GE

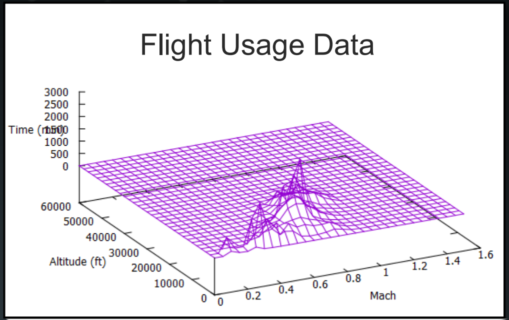
② DOE of $\triangle P_{ult}$
$= f(\text{Mach, Alt, Temp}, P_{ss}, P_0, P_{hs}, \text{etc.})$

③ Surrogate model of $\triangle P_{ult}$
$= f(\text{Mach, Alt, Temp})$

④ MCS by JMP Profiler

⑤ Search for Design Load $\triangle P_{ult}$

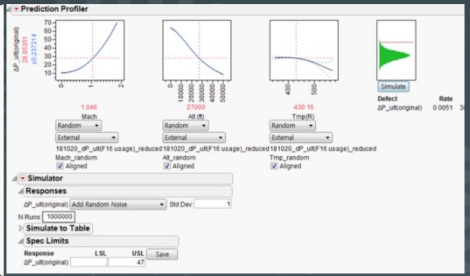
END



PDF of Temp

PDF of Mach

PDF of Alt



Prediction Profiler

Mach: 1.046 — Random; External; 181020_dP_ult(F16 usage)_reduced; Mach_random; ☑ Aligned

Alt (ft): 27000 — Random; External; 181020_dP_ult(F16 usage)_reduced; Alt_random; ☑ Aligned

Tmp(R): 430.16 — Random; External; 181020_dP_ult(F16 usage)_reduced; Tmp_random; ☑ Aligned

Defect	Rate
ΔP_ult(original)	0.0051

Simulator

Responses

ΔP_ult(original): Add Random Noise; Std Dev: 1

N Runs: 1000000

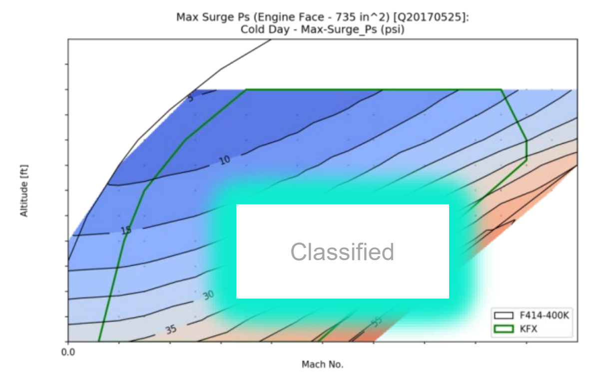
Simulate to Table

Spec Limits

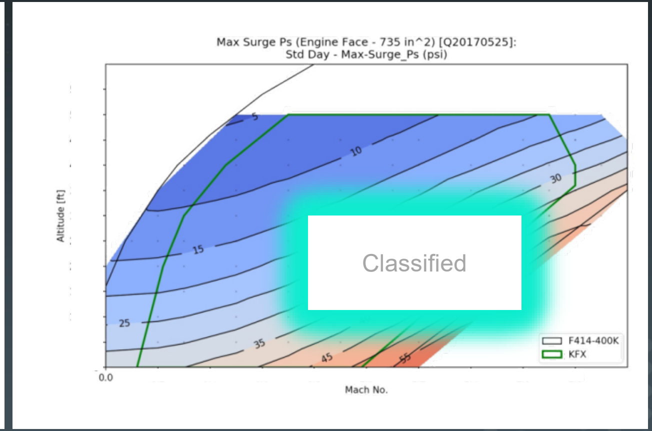
Response	LSL	USL
ΔP_ult(original)		47

① P_{hs} Data at Engine Face from GE

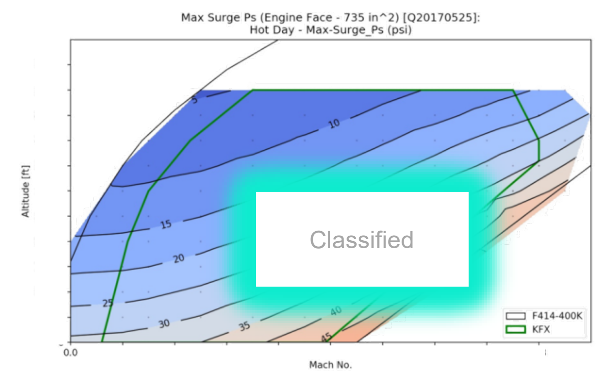
- **Hammershock pressure at engine face was provided from GE throughout Mach and altitude**
- **20% Cold/STD/20% Hot day data were considered for analysis**



Cold Day



Standard Day



Hot Day

② DOE of △P_{ult}

- $P_{hs,peak}$ is the max peak value in a duct when the hammershock(HS) occurs
- $P_{hs,peak}$ is analyzed by engine cycle deck, GE HS and theoretical method
- Ultimate pressure : △Pult = 1.5 x ($P_{hs,peak}$ – P0)

Hammershock Load Analysis for C109PQL of KF-X Using F414 Engine Cycle Deck Results @ 20% Cold Day

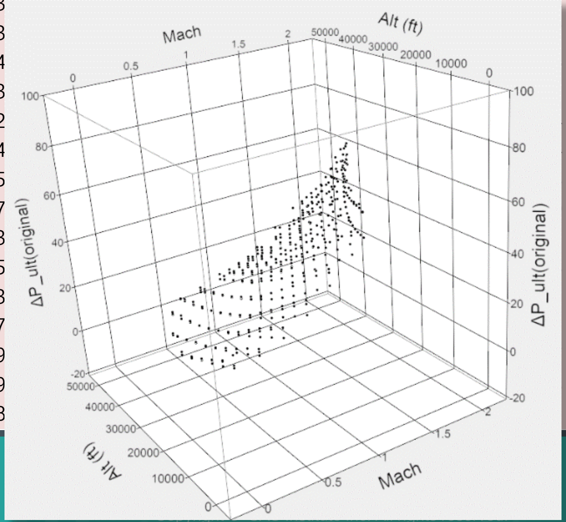
Acap 820 **Ath** 635 **A2** 735

Pth,hs*ratio
(Pth,hs -2psi)/Pth,hs
0.0319

: 2psi => delta (CFD

ZXM	ZALT	PAMB (P0)	Ts_amb(R)	TT(R)	PT0	Ps2,hs	HSRatio@2	OverP Ratio	HSRatio@th	PT_th	Ps_th (Pss)	Pth,hs (Phs)	Pth,hs* Pth,hs*ratio	ΔP_ult(corrected) (ΔP_ult)
1.104	0	14.70	399.87	497.57	31.53	55.00	1.89	1.065	2.009	31.75	29.33	58.93	57.05	63.53
1.12	1000	14.17	399.32	499.73						31.21	28.76	58.89	57.02	64.26
1.136	2000	13.66	398.77	501.93						30.67	28.20	58.86	56.98	64.97
1.153	3000	13.17	398.22	504.34						30.18	27.69	57.75	55.91	64.11
1.17	4000	12.69	405.56	516.83						29.69	27.17	56.64	54.83	63.21
1.188	5000	12.23	415.99	533.62						29.24	26.63	56.57	54.76	63.80
1.206	6000	11.78	426.41	550.64						28.78	26.10	55.44	53.67	62.84
1.225	7000	11.34	431.79	561.55						28.32	25.56	56.44	54.64	64.94
1.244	8000	10.92	430.69	564.17						27.86	25.05	56.37	54.57	65.48
1.263	9000	10.51	429.59	566.83						27.43	24.56	56.30	54.50	66.00
1.283	10000	10.11	428.5	569.75						27.04	24.12	55.18	53.42	64.97
1.304	11000	9.72	427.4	572.93						26.72	23.83	54.12	52.39	64.01
1.325	12000	9.35	426.3	576.17						26.40	23.55	55.19	53.43	66.12
1.347	13000	8.98	425.2	579.69						26.11	23.31	53.07	51.38	63.59
1.37	14000	8.63	422.42	581.19						25.86	23.10	53.08	51.39	64.13
1.393	15000	8.29	419.41	582.38						25.61	22.90	52.03	50.37	63.12

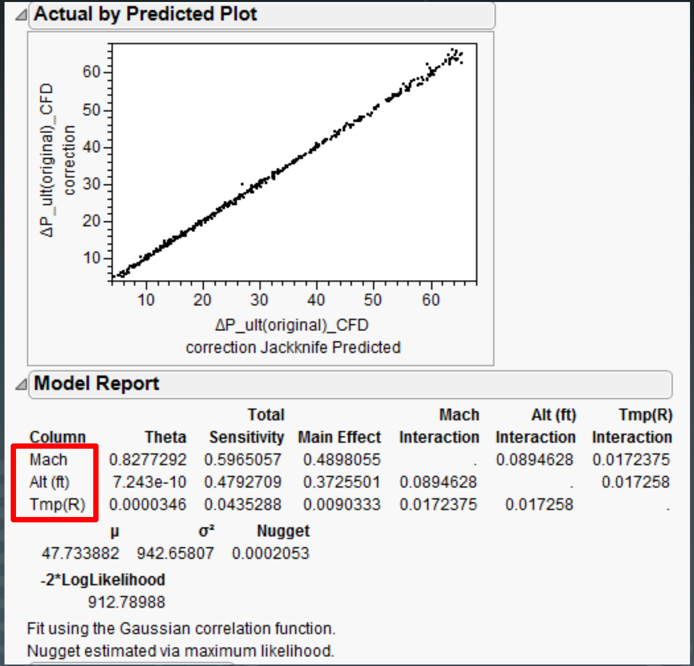
$P_{hs,peak}$



※ MCS : Monte Carlo Simulation

③ Surrogate model of △P_{ult}

- Create the surrogate model of △P_{ult} (Mach,Alt,Temp), for example, kriging
- JMP provides a surrogate model for MCS



Actual by Predicted Plot

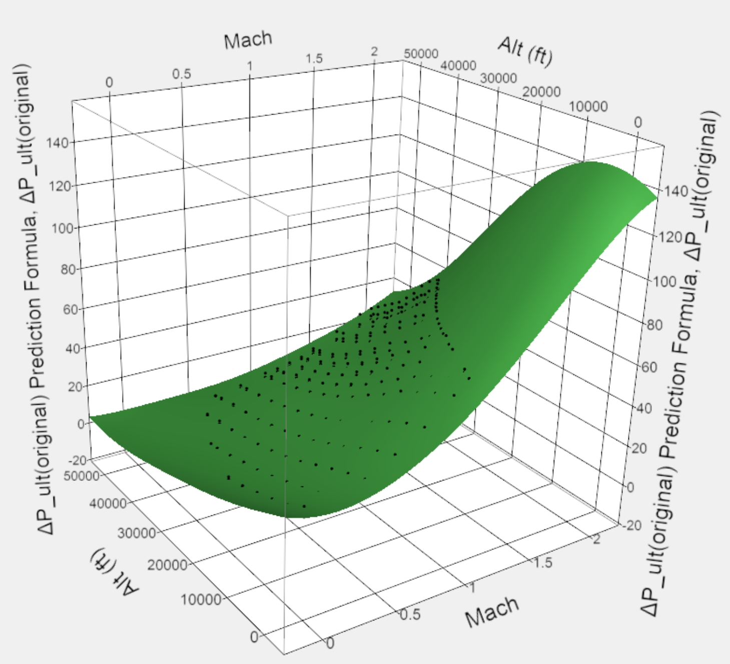
Model Report

Column	Theta	Total Sensitivity	Main Effect	Mach Interaction	Alt (ft) Interaction	Tmp(R) Interaction
Mach	0.8277292	0.5965057	0.4898055	.	0.0894628	0.0172375
Alt (ft)	7.243e-10	0.4792709	0.3725501	0.0894628	.	0.017258
Tmp(R)	0.0000346	0.0435288	0.0090333	0.0172375	0.017258	.

μ	σ²	Nugget
47.733882	942.65807	0.0002053

-2*LogLikelihood
912.78988

Fit using the Gaussian correlation function.
Nugget estimated via maximum likelihood.



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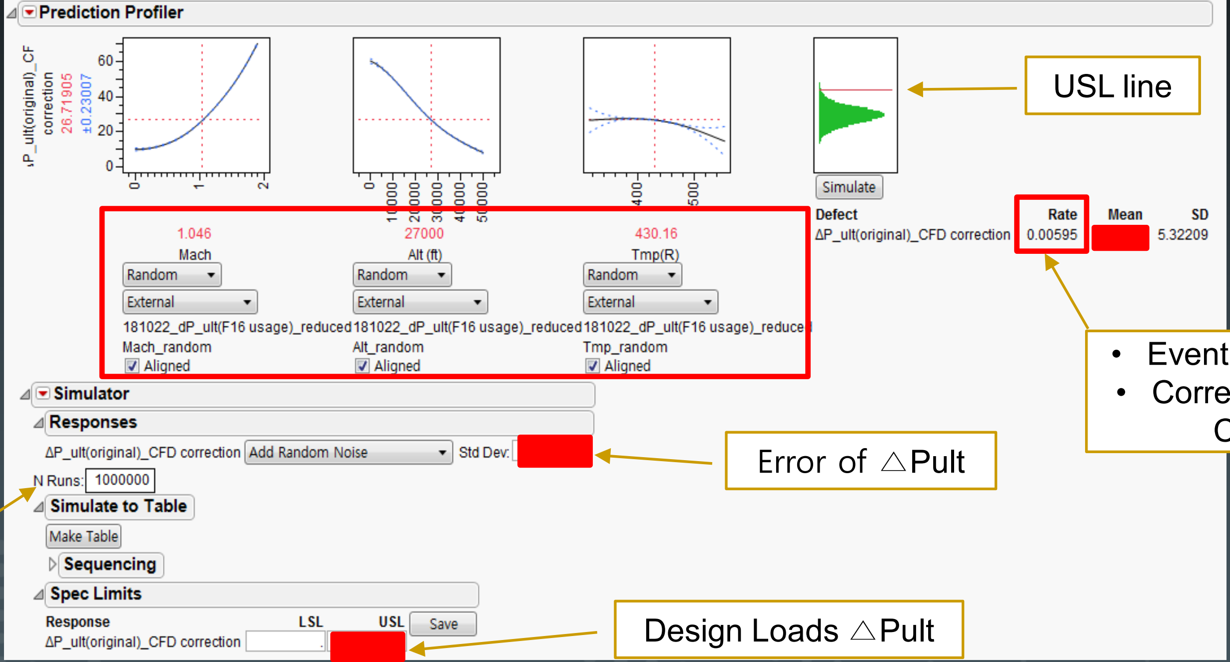
※ MCS : Monte Carlo Simulation

④ MCS & ⑤ Search for △Pult

- **Performed MCS by JMP**
- **Enter the pdf of Mach/Alt/Temp, no. of Runs, USL(upper spec limit)**



Prediction Profiler

1.046	27000	430.16
Mach	Alt (ft)	Tmp(R)
Random	Random	Random
External	External	External
181022_dP_ult(F16 usage)_reduced	181022_dP_ult(F16 usage)_reduced	181022_dP_ult(F16 usage)_reduce
Mach_random	Alt_random	Tmp_random
☑ Aligned	☑ Aligned	☑ Aligned

Simulate

Defect	Rate	Mean	SD
ΔP_ult(original)_CFD correction	0.00595	[redacted]	5.32209

Simulator

Responses

ΔP_ult(original)_CFD correction: Add Random Noise; Std Dev: [redacted]

N Runs: 1000000

Simulate to Table

Make Table

Sequencing

Spec Limits

Response	LSL	USL
ΔP_ult(original)_CFD correction		[redacted]

Save

USL line

- Event Rate Over USL
- Correspond to Loads Criteria: 10^{-7}

Error of △Pult

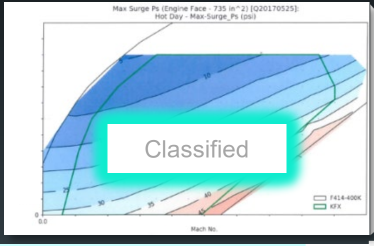
MCS Samples (1 Million)

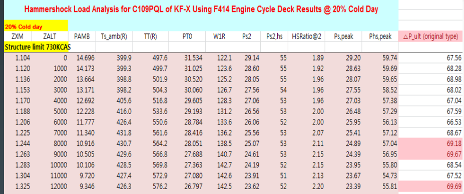
Design Loads △Pult

※ MCS : Monte Carlo Simulation

Proposed Probabilistic Work Flow

- **Search for Design Pressure ΔPult**





Hammershock Load Analysis for C109PQL of KF-X Using F414 Engine Cycle Deck Results @ 20% Cold Day

20% Cold day

ZXM	ZALT	PAMB	Ts_amb(R)	TT(R)	PT0	W1R	Ps2	Ps2,hs	HSRatio@2	Ps,peak	Phs,peak	△P_ult (original type)
Structure limit 730KCAS												
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1.120	1000	14.173	399.3	499.7	31.025	123.6	28.60	55	1.92	28.63	59.69	68.28
1.136	2000	13.664	398.8	501.9	30.520	125.2	28.05	55	1.96	28.07	59.65	68.98
1.153	3000	13.171	398.2	504.3	30.060	126.7	27.56	54	1.96	27.55	58.52	68.02
1.170	4000	12.692	405.6	516.8	29.605	128.3	27.06	53	1.96	27.03	57.38	67.04
1.188	5000	12.228	416.0	533.6	29.193	131.2	26.56	53	2.00	26.48	57.29	67.59
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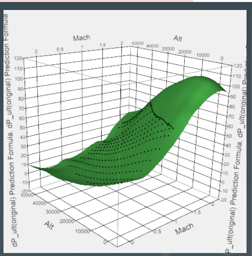
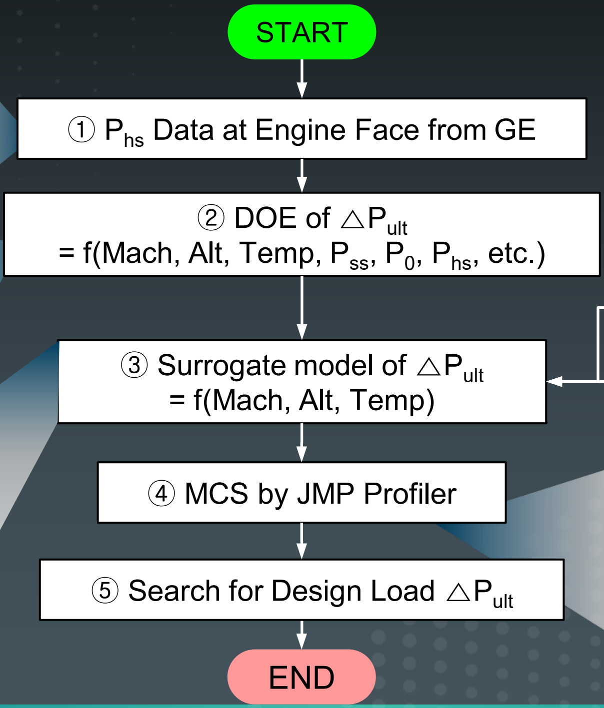
1.283	10000	10.106	428.5	569.8	27.363	142.7	24.19	52	2.15	23.95	55.80	68.54
1.304	11000	9.720	427.4	572.9	27.080	142.6	23.91	51	2.13	23.67	54.73	67.52
1.325	12000	9.346	426.3	576.2	26.797	142.5	23.62	52	2.20	23.39	55.81	69.69
1.347	13000	8.984	425.2	579.7	26.551	142.2	23.38	50	2.14	23.15	53.67	67.03





START

① P_{hs} Data at Engine Face from GE

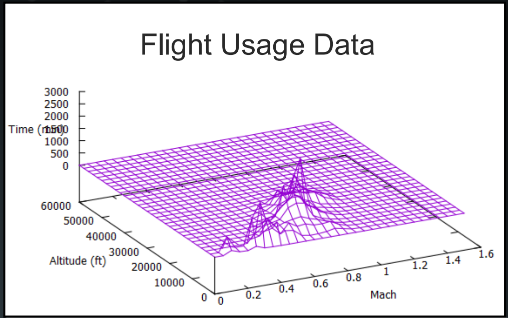
② DOE of $\triangle P_{ult}$
= f(Mach, Alt, Temp, P_{ss}, P_0, P_{hs}, etc.)

③ Surrogate model of $\triangle P_{ult}$
= f(Mach, Alt, Temp)

④ MCS by JMP Profiler

⑤ Search for Design Load $\triangle P_{ult}$

END

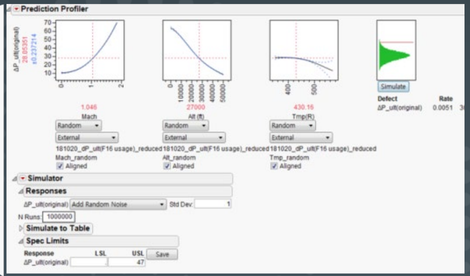


Flight Usage Data

PDF of Temp

PDF of Mach

PDF of Alt



Prediction Profiler

Mach: 1.046
Alt (ft): 27000
Tmp(R): 430.16

Mach	Alt (ft)	Tmp(R)
Random	Random	Random
External	External	External
181020_dP_ult(F16 usage)_reduced	181020_dP_ult(F16 usage)_reduced	181020_dP_ult(F16 usage)_reduced
Mach_random	Alt_random	Tmp_random
☑ Aligned	☑ Aligned	☑ Aligned

Defect	Rate
ΔP_ult(original)	0.0051

Simulator

Responses

ΔP_ult(original) Add Random Noise Std Dev: 1

N Runs: 1000000

Simulate to Table

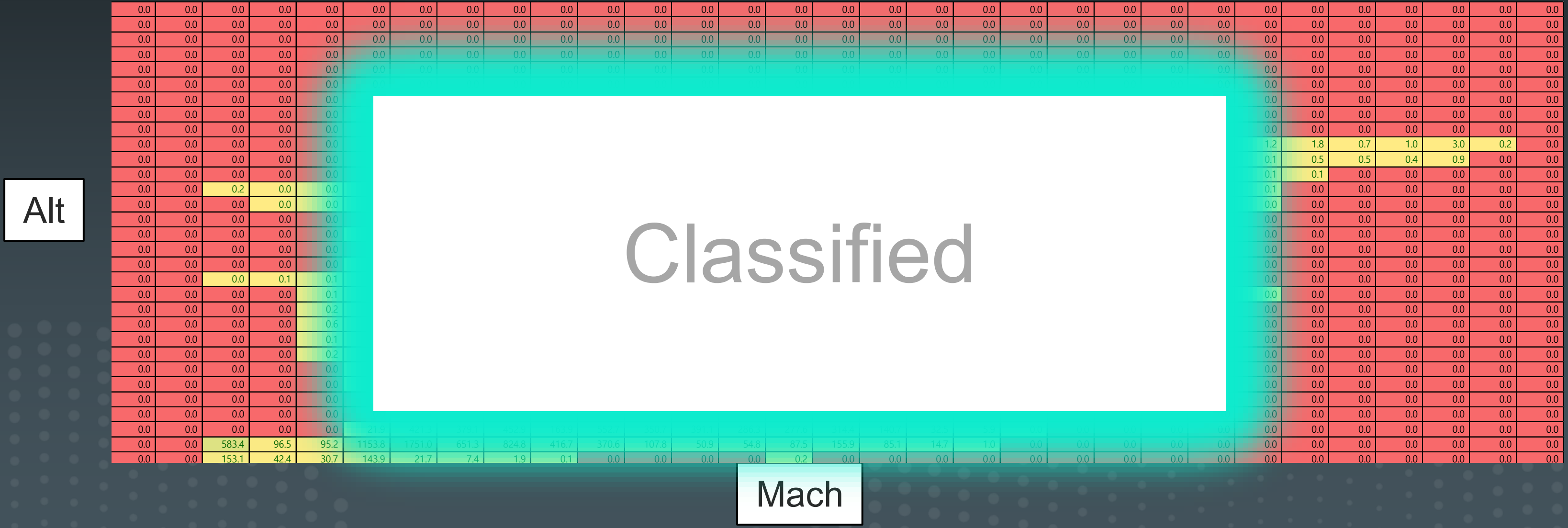
Spec Limits

Response	LSL	USL
ΔP_ult(original)		47

Save

Mach/Alt of Flight Usage

- **ROKAF Flight Usage Data**
  - Year 1997 – 2002
  - Number is the minute which aircrafts stayed at Mach/Alt



Alt

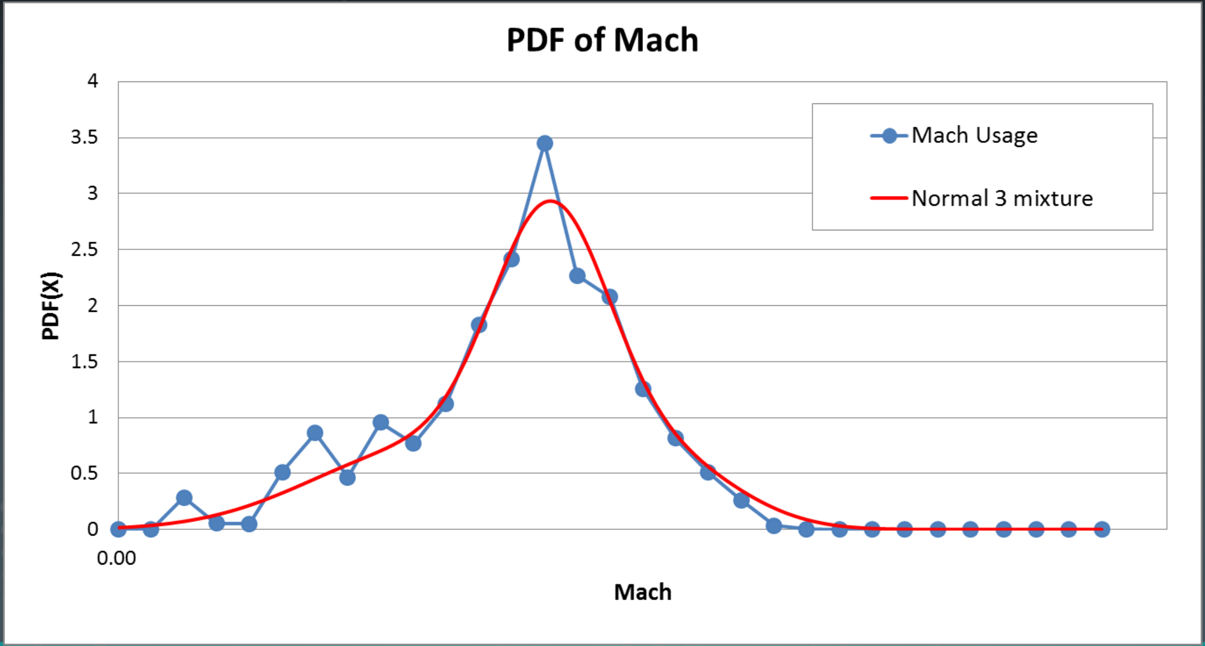
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.2	1.8	0.7	1.0	3.0	0.2	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.1	0.5	0.5	0.4	0.9	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.1	0.1	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.2	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.1	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.6	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	583.4	96.5	95.2	1153.8	1751.0	651.3	824.8	416.7	370.6	107.8	50.9	54.8	87.5	155.9	85.1	14.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	153.1	42.4	30.7	143.9	21.7	7.4	1.9	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Classified

Mach

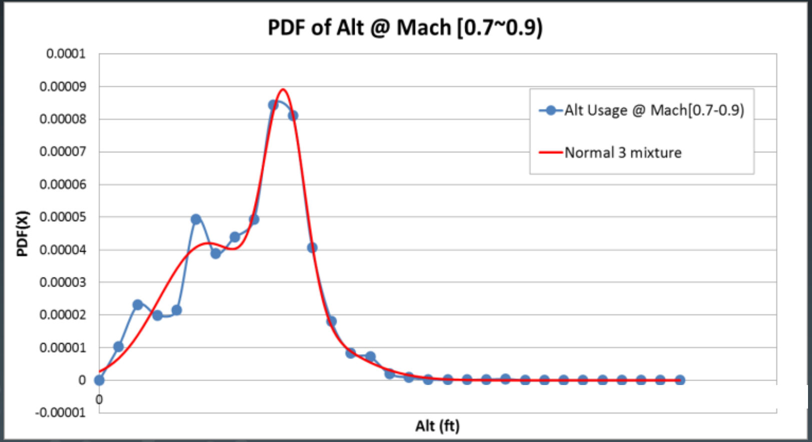
Randomize Mach/Alt of Flight Usage … cont'd

- **Determine PDF of Mach**
  - Find PDF of Mach as close as flight usage shape

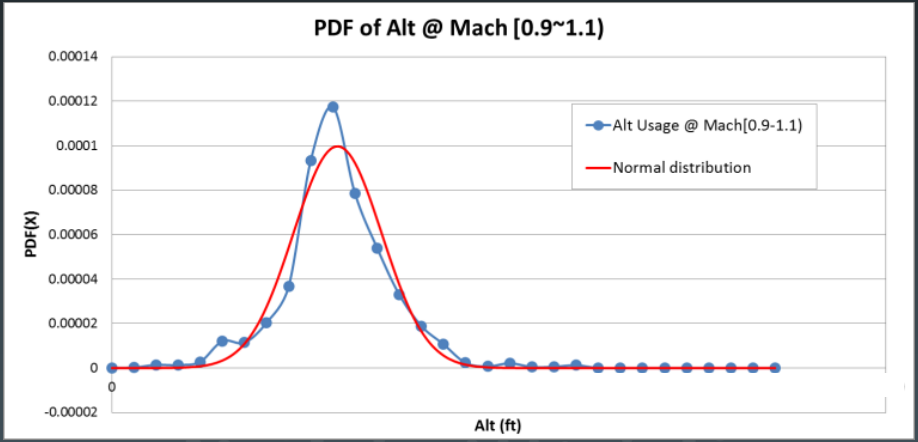


Randomize Mach/Alt of Flight Usage

- **Determine PDF of Alt for specific Mach range**
  - Find PDF of Alt as close as flight usage shape



0.7<Mach<0.9



0.9<Mach<1.1

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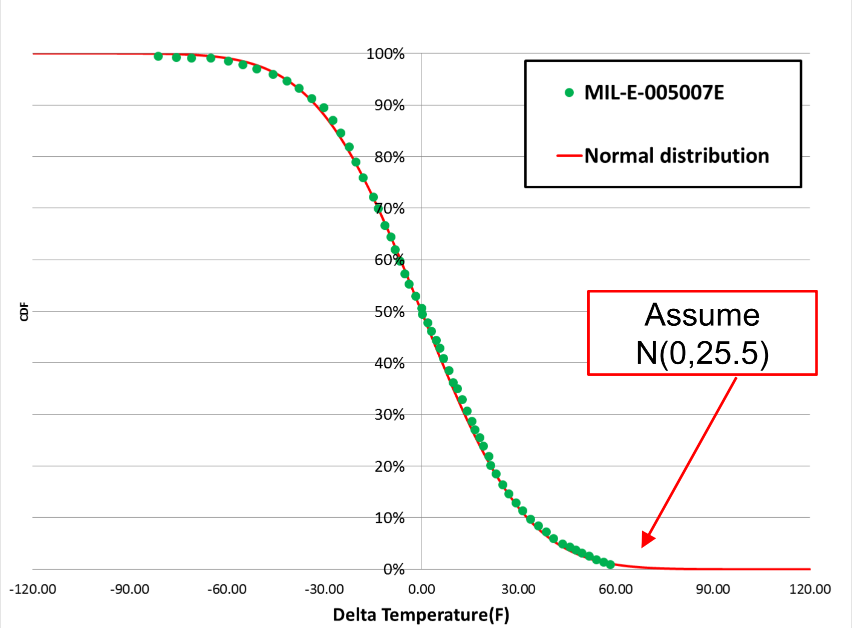
Randomize Temperature

- **Consider CDF of delta temperature from standard day**
  - Find CDF of Temp as close as MIL-E-005007E



[Ref.] MIL-E-005007E, Engines, Aircraft, Turbojet and Turbofan, General Specification For, 1983

Hammershock Event Rate ... cont'd

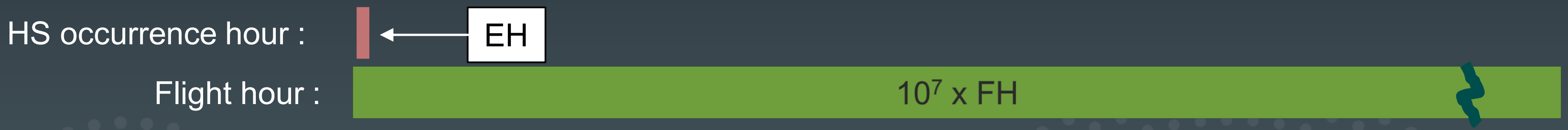
- **Limit loads frequency criteria (JSSG-2006)**
  - "All loads resulting from failures whose frequency of occurrence is greater than or equal to 1×10^{-7} per flight shall be **limit loads**"
  - That is, if some loads conditions happen more than once per 10^7 flight, we should contain those as design loads
  - That is, if some loads conditions happen less than once per 10^7 flight, we should not contain those as design loads

- **Hammershock event for GE engine**
  - GE provided hammershock (HS) event for GE-XXX engine
  - One engine stalls in specific 'EH' flight hours
  - Because a fighter has two engines, the occurrence of HS = $\dfrac{2 \text{ event}}{\text{EH hour}}$

Hammershock Event Rate

- **Max Allowable Hammershock Event Rate (MAER)**
  - Convert the loads criteria “once per 10^7 flight” to the “rate”
  - For one engine, allowable HS event rate is calculated in considering one engine stall rate

$$\frac{1\ \text{HS}}{10^7\,\text{flight}} \times \frac{1\ \text{flight}}{\text{FH hour}} \times \frac{\text{EH} \quad \text{hour}}{1\ \text{HS}} = 0.00615$$


HS occurrence hour :

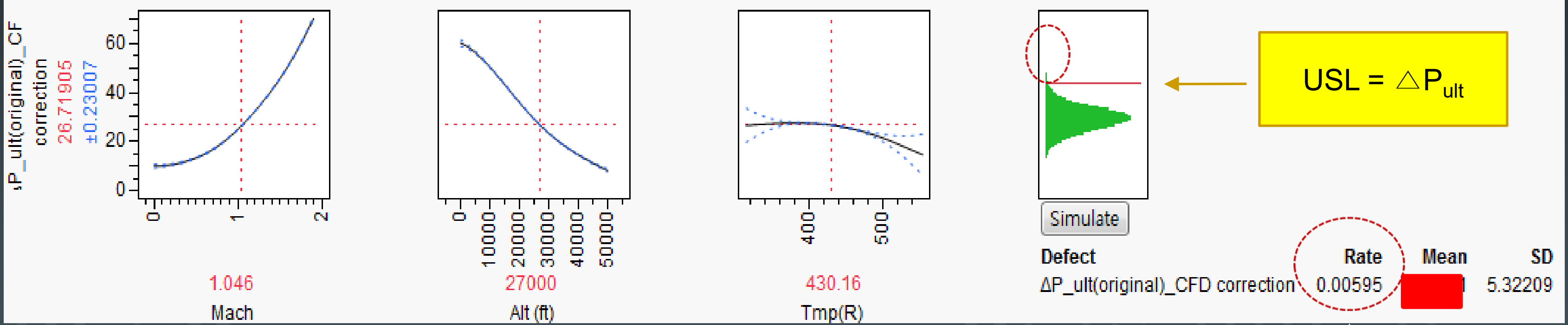
EH

Flight hour :

10^7 x FH

Inlet Hammershock Pressure for Design

- △Pult inlet hammershock for inlet design
  - Input USL value and run JMP simulator
  - Compare the probability (Rate) with allowable HS event rate (MAER)
  - Finally, △Pult for inlet design is xx psid



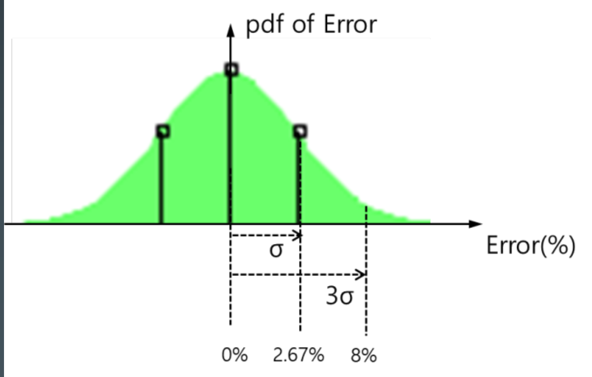
USL = $\triangle P_{ult}$

```
Defect                                  Rate      Mean         SD
ΔP_ult(original)_CFD correction      0.00595   [redacted]   5.32209
```

Less than MAER 0.00615

Noise of Hammershock Pressure … cont'd

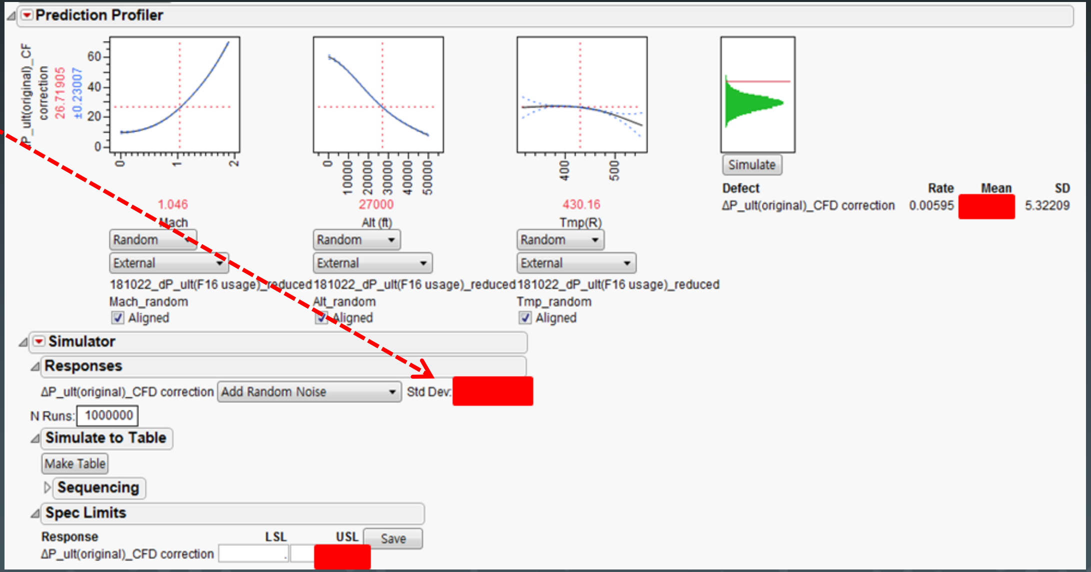
- **Noise of engine stall pressure ratio (SPR)**
  - Refer to paper : "Impact of a Probabilistic Approach on Inlet Hammershock Design Loads", 1999, AIAA
  - The variability of SPR was assumed to be a normal distribution with a 3σ value of +/-8% of mean
  - If the 8% error occurs at 3σ, the 2.67% error is at σ
  - Therefore, 3% error at σ is assumed for inlet hammershock



Noise of Hammershock Pressure

- **Noise for inlet hammershcok**
  - Add the noise to the inlet hammershock results after GE comments
  - Noise is the normal random with 3% error at σ

$\sigma = 0.03 \times \text{Mean}(\triangle P\_ult)$ [psi]



Prediction Profiler

Mach	Alt (ft)	Tmp(R)
1.046	27000	430.16
Random	Random	Random
External	External	External
181022_dP_ult(F16 usage)_reduced Mach_random	181022_dP_ult(F16 usage)_reduced Alt_random	181022_dP_ult(F16 usage)_reduced Tmp_random
☑ Aligned	☑ Aligned	☑ Aligned

Simulate

Defect	Rate	Mean	SD
ΔP_ult(original)_CFD correction	0.00595	[redacted]	5.32209

Simulator

Responses

ΔP_ult(original)_CFD correction: Add Random Noise, Std Dev: [redacted]

N Runs: 1000000

Simulate to Table

Make Table

Sequencing

Spec Limits

Response	LSL	USL
ΔP_ult(original)_CFD correction	.	[redacted]

Save

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△P_{ult} Result Summary

- **△Pult inlet hammershock according to methodology**
  - With probabilistic method, inlet design hammershock pressure will be reduced from xx psid to yy psid

No.	Method	△P_ult (psid)	Flight Cond.	Remark
1	Deterministic	xx	M1.1/SL 20% Cold day	
2	Probabilistic (RV: Mach, Alt, Temp.)	yy	500 ~ 550 knot	• Reduced by about 30% from Deterministic

※ RV : Random Variable

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DISCOVERY SUMMIT

EXPLORING DATA
INSPIRING INNOVATION

jmp