Access Denied?
The Sino-American Contest for Military Primacy in Asia

Technical Appendix

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This document contains a set of technical appendices which accompany the article, "Access Denied? The Sino-American Contest for Military Primacy in Asia," *International Security*, Vol. 50, No. 1 (Summer 2025), pp. 118-151. The table of contents for the appendices is as follows:

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A) Complete Results

This section presents full and detailed results for each of the analyses we present in the article.[1] Tables A1a and A1b present our full results by day and by base for the first set of results: U.S. 6 Bases (see Figure 2 in the article).

Table A1a: Full Results by Day, U.S. 6 Bases Scenario

Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	72.6	5.9	66.0	0.7	5.9	144.0	95.6
2	58.9	5.0	53.2	0.7	5.8	144.0	95.9
3	48.0	4.2	43.1	0.7	5.8	144.0	96.3
4	39.3	3.5	35.1	0.7	5.8	144.0	96.6
5	32.6	2.9	29.0	0.7	5.8	113.3	69.3
6	27.2	2.4	24.1	0.7	5.7	82.8	42.2
7	22.4	2.0	19.7	0.7	5.7	60.4	22.4
8	17.2	1.6	14.9	0.7	5.7	41.8	6.0
9	14.5	1.2	12.6	0.7	5.6	25.6	0.0
10	13.6	1.1	11.0	1.5	5.1	11.9	0.0
11	11.7	0.8	9.7	1.2	4.0	6.9	0.0
12	10.0	0.8	8.4	0.8	2.9	3.7	0.0
13	8.1	0.5	7.2	0.3	2.7	1.0	0.0
14	7.2	0.5	6.4	0.3	2.7	0.5	0.0
15	5.9	0.4	5.3	0.3	2.6	0.5	0.0
16	4.8	0.2	4.4	0.2	2.6	0.5	0.0
17	4.4	0.2	3.9	0.2	2.6	0.5	0.0
18	3.8	0.1	3.5	0.1	2.6	0.4	0.0
19	3.1	0.1	2.9	0.1	2.6	0.4	0.0
20	2.8	0.1	2.6	0.1	2.6	0.4	0.0
21	2.6	0.1	2.4	0.1	2.6	0.4	0.0
22	2.4	0.1	2.2	0.0	2.5	0.4	0.0
23	2.2	0.1	2.1	0.0	2.5	0.4	0.0
24	2.0	0.1	1.9	0.0	2.5	0.4	0.0
25	1.7	0.0	1.7	0.0	2.5	0.4	0.0
26	1.6	0.0	1.6	0.0	2.5	0.4	0.0
27	1.4	0.0	1.4	0.0	2.5	0.4	0.0
28	1.3	0.0	1.3	0.0	2.4	0.4	0.0

[1] The supplementary files accompanying the article include the model itself (.xlsx), which is set up to replicate all results presented here. The supplementary files also include full results in Excel format (.xlsx), which include the key inputs needed to replicate each set of results.

29	0.6	0.0	0.6	0.0	2.4	0.4	0.0
30	0.2	0.0	0.2	0.0	2.4	0.3	0.0
Total	**424.3**	**34.1**	**378.5**	**11.6**	**109.4**	**930.4**	**524.2**

Table A1b: Full Results by Base, U.S. 6 Bases Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	111	109.1	0.0	106.1	3.0
Kadena AB	178	164.9	11.9	145.6	7.4
Iwakuni MCAS	22	21.8	0.0	21.7	0.0
Futenma MCAS	14	12.1	0.0	11.4	0.7
Misawa AB	47	42.9	22.2	20.4	0.3
Yokota AB	78	73.5	0.0	73.3	0.1

Tables A2a and A2b present our full results by day and by base for our second set of results: Dispersed to 15 Bases (see Figure 2 in the article).

Table A2a: Full Results by Day, Dispersed to 15 Bases Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	55.9	8.2	46.9	0.7	5.9	144.0	95.6
2	44.8	7.0	37.1	0.7	5.8	144.0	95.9
3	36.9	5.7	30.5	0.7	5.8	144.0	96.3
4	30.8	4.7	25.4	0.7	5.8	144.0	96.6
5	25.9	3.7	21.5	0.7	5.8	137.6	91.2
6	22.3	3.3	18.3	0.7	5.7	115.8	71.9
7	19.3	2.8	15.8	0.7	5.7	96.8	55.2
8	16.8	2.3	13.8	0.7	5.7	80.6	40.9
9	14.1	1.2	12.2	0.7	5.6	68.1	30.0
10	10.5	0.4	9.4	0.7	5.6	56.9	20.3
11	8.0	0.2	7.0	0.7	5.6	48.2	12.8
12	4.7	0.1	3.9	0.7	5.5	41.9	7.3
13	3.7	0.1	2.9	0.7	5.5	38.0	4.1
14	3.4	0.1	2.6	0.7	5.5	34.5	1.3
15	3.4	0.1	2.4	0.9	5.3	31.2	0.0
16	3.5	0.1	2.2	1.1	5.1	28.0	0.0
17	3.3	0.1	2.0	1.1	5.0	26.7	0.0
18	3.0	0.1	1.8	1.1	5.0	25.6	0.0
19	2.7	0.0	1.5	1.1	5.0	24.4	0.0
20	2.6	0.0	1.4	1.1	5.0	23.2	0.0
21	1.7	0.0	0.5	1.1	4.9	22.1	0.0
22	1.4	0.0	0.2	1.1	4.9	20.9	0.0
23	1.4	0.0	0.2	1.1	4.9	19.8	0.0
24	1.4	0.0	0.2	1.1	4.9	18.7	0.0
25	1.3	0.0	0.2	1.1	4.8	17.5	0.0
26	1.5	0.0	0.0	1.5	4.7	16.4	0.0
27	1.5	0.0	0.0	1.5	4.6	14.9	0.0
28	1.5	0.0	0.0	1.5	4.6	13.3	0.0
29	1.5	0.0	0.0	1.5	4.6	11.8	0.0
30	1.2	0.0	0.0	1.2	3.5	10.3	0.0
Total	**329.6**	**40.3**	**260.0**	**29.3**	**156.2**	**1,619.3**	**719.3**

Table A2b: Full Results by Base, Dispersed to 15 Bases Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	57	37.0	0.0	33.0	4.0
Kadena AB	97	83.4	11.3	69.1	3.0
Chitose JASDF AB	39	23.1	5.5	16.3	1.3
Yokota AB	38	11.4	0.0	7.1	4.3
Misawa AB	75	67.5	16.9	50.4	0.2
Komatsu JASDF AB	14	8.6	5.3	1.1	2.2
Guam International	15	9.5	0.0	6.9	2.6
Clark AB	32	28.3	0.0	28.3	0.0
Komaki JASDF AB	15	7.5	0.0	3.6	3.9
Villamor PAF AB	17	14.2	0.0	12.8	1.4
Naha JASDF AB	17	14.3	1.3	11.6	1.3
Atsugi JMSDF AB	10	4.9	0.0	1.8	3.1
Iwakuni MCAS	12	11.5	0.0	11.5	0.0
Miho JASDF AB	6	5.8	0.0	5.6	0.2
Iruma JASDF AB	6	2.7	0.0	0.9	1.8

Tables A3a and A3b present our full results by day and by base for our third set of results: Dispersed to 24 Bases (see Figures 2 and 5 in the article).

Table A3a: Full Results by Day, Dispersed to 24 Bases Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	56.7	9.1	46.9	0.7	5.9	144.0	95.6
2	44.0	7.8	35.5	0.7	5.8	144.0	95.9
3	34.8	6.2	27.9	0.7	5.8	144.0	96.3
4	28.4	5.1	22.7	0.7	5.8	144.0	96.6
5	23.2	3.8	18.6	0.7	5.8	142.1	95.2
6	19.7	3.3	15.7	0.7	5.7	122.7	78.1
7	17.1	2.9	13.5	0.7	5.7	106.0	63.4
8	15.2	2.6	11.9	0.7	5.7	91.9	51.1
9	12.8	1.9	10.3	0.7	5.6	80.8	41.4
10	10.4	1.3	8.4	0.7	5.6	71.2	33.2
11	6.7	0.2	5.8	0.7	5.6	62.8	25.9
12	4.9	0.2	4.0	0.7	5.5	57.3	21.2
13	4.3	0.2	3.4	0.7	5.5	52.8	17.5
14	4.0	0.3	3.0	0.7	5.5	48.9	14.2
15	3.3	0.1	2.5	0.7	5.5	46.1	12.0
16	2.7	0.1	1.9	0.7	5.4	45.1	11.4
17	1.1	0.1	0.3	0.7	5.4	44.5	11.1
18	1.1	0.1	0.3	0.7	5.4	43.8	10.8
19	1.0	0.1	0.2	0.7	5.4	43.2	10.5
20	0.8	0.1	0.0	0.7	5.3	42.6	10.2
21	0.7	0.0	0.0	0.7	5.3	41.9	10.0
22	0.7	0.0	0.0	0.7	5.3	41.3	9.7
23	0.7	0.0	0.0	0.7	5.3	40.7	9.4
24	0.7	0.0	0.0	0.7	5.2	40.0	9.1
25	0.7	0.0	0.0	0.7	5.2	39.4	8.8
26	0.7	0.0	0.0	0.7	5.2	38.7	8.5
27	0.7	0.0	0.0	0.7	5.2	38.1	8.2
28	0.7	0.0	0.0	0.7	5.1	37.5	7.9
29	0.7	0.0	0.0	0.7	5.1	36.8	7.6
30	0.7	0.0	0.0	0.7	5.1	36.2	7.3
Total	**299.1**	**45.8**	**232.8**	**20.5**	**164.0**	**2,068.4**	**978.0**

Table A3b: Full Results by Base, Dispersed to 24 Bases Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	46	25.3	0.0	21.4	3.9
Kadena AB	85	67.3	11.2	53.4	2.7
Chitose JASDF AB	35	19.2	5.6	12.2	1.4
Yokota AB	34	8.2	0.0	4.8	3.5
Misawa AB	75	68.5	17.9	50.5	0.2
Komatsu JASDF AB	14	8.2	5.4	1.2	1.6
Guam International	13	6.6	0.0	5.2	1.5
Clark AB	27	21.4	0.0	21.4	0.0
Villamor PAF AB	14	9.7	0.0	9.0	0.7
Cesar Basa PAF AB	5	3.8	1.3	2.2	0.3
Komaki JASDF AB	12	3.3	0.0	2.3	1.0
Naha JASDF AB	15	10.5	1.2	8.6	0.7
Atsugi JMSDF AB	8	1.6	0.0	0.8	0.8
Iwakuni MCAS	12	11.6	0.0	11.6	0.0
Miho JASDF AB	5	4.3	0.0	4.3	0.1
Iruma JASDF AB	5	1.0	0.0	0.6	0.4
Gifu JASDF AB	4	1.2	0.0	1.0	0.2
Saipan International	4	1.9	0.0	1.7	0.2
Kanoya JMSDF AB	12	12.0	0.0	12.0	0.0
Futenma MCAS	6	3.8	0.0	3.5	0.3
Hamamatsu JASDF AB	5	1.2	0.0	0.7	0.5
Nyuutabaru JASDF AB	5	3.6	1.2	2.3	0.2
Tsuiki JASDF AB	5	3.9	2.0	1.8	0.1
Hyakuri JASDF AB	4	0.7	0.0	0.5	0.3

Tables A3c and A3d present full results by day and by base for our fourth set of results: Dispersed to 24 Bases but with enhanced U.S. jamming capabilities, and therefore lower People's Liberation Army (PLA) missile accuracy (see Figure 2 in the article). Here we assume the PLA's Short- and Medium-Range Ballistic Missiles (SRBM & MRBM) have a circular error probable (CEP) of 45 meters rather than our baseline of 20 meters. We also assume that their cruise missiles have a CEP of 45 meters rather than our baseline of 10 meters.

Table A3c: Full Results by Day, Dispersed to 24 Bases Scenario, Low PLA Missile Accuracy Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	48.5	1.9	45.9	0.7	5.9	144.0	95.6
2	37.1	1.9	34.5	0.7	5.8	144.0	95.9
3	29.0	1.5	26.8	0.7	5.8	144.0	96.3
4	23.3	1.1	21.5	0.7	5.8	144.0	96.6
5	18.9	0.7	17.5	0.7	5.8	144.0	96.9
6	15.8	0.4	14.6	0.7	5.7	144.0	97.3
7	13.3	0.0	12.6	0.7	5.7	139.7	93.7
8	11.8	0.0	11.1	0.7	5.7	128.7	84.2
9	10.4	0.0	9.7	0.7	5.6	119.0	75.8
10	8.6	0.0	7.9	0.7	5.6	110.3	68.3
11	6.1	0.0	5.4	0.7	5.6	102.7	61.8
12	4.3	0.0	3.7	0.7	5.5	97.6	57.5
13	3.8	0.0	3.1	0.7	5.5	93.5	54.1
14	3.4	0.0	2.7	0.7	5.5	90.2	51.4
15	2.9	0.0	2.2	0.7	5.5	86.8	48.7
16	2.4	0.0	1.7	0.7	5.4	84.3	46.6
17	1.0	0.0	0.3	0.7	5.4	82.2	45.1
18	1.0	0.0	0.3	0.7	5.4	81.3	44.5
19	0.8	0.0	0.2	0.7	5.4	80.4	44.0
20	0.7	0.0	0.0	0.7	5.3	79.7	43.7
21	0.7	0.0	0.0	0.7	5.3	79.1	43.4
22	0.7	0.0	0.0	0.7	5.3	78.5	43.1
23	0.7	0.0	0.0	0.7	5.3	77.9	42.9
24	0.7	0.0	0.0	0.7	5.2	77.3	42.6
25	0.7	0.0	0.0	0.7	5.2	76.6	42.3
26	0.7	0.0	0.0	0.7	5.2	76.3	42.3
27	0.7	0.0	0.0	0.7	5.2	75.7	42.1
28	0.7	0.0	0.0	0.7	5.1	75.1	41.8
29	0.7	0.0	0.0	0.7	5.1	74.5	41.5
30	0.7	0.0	0.0	0.7	5.1	73.9	41.3
Total	**249.8**	**7.5**	**221.7**	**20.5**	**164.0**	**3,005.4**	**1,821.3**

Table A3d: Full Results by Base, Dispersed to 24 Bases Scenario, Low PLA Missile Accuracy Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	46	25.3	0.0	21.4	3.9
Kadena AB	85	56.8	1.9	50.7	4.2
Chitose JASDF AB	35	14.4	0.8	11.2	2.4
Yokota AB	34	8.0	0.0	4.9	3.1
Misawa AB	75	50.2	2.7	45.0	2.5
Komatsu JASDF AB	14	2.6	0.8	0.9	0.9
Guam International	13	5.7	0.0	5.2	0.5
Clark AB	27	21.5	0.0	21.5	0.0
Villamor PAF AB	14	8.8	0.0	8.5	0.3
Cesar Basa PAF AB	5	2.7	0.4	2.1	0.2
Komaki JASDF AB	12	2.6	0.0	2.2	0.4
Naha JASDF AB	15	8.8	0.2	8.2	0.4
Atsugi JMSDF AB	8	1.1	0.0	0.7	0.4
Iwakuni MCAS	12	11.6	0.0	11.6	0.0
Miho JASDF AB	5	4.3	0.0	4.3	0.0
Iruma JASDF AB	5	0.7	0.0	0.5	0.2
Gifu JASDF AB	4	1.0	0.0	0.9	0.1
Saipan International	4	1.8	0.0	1.7	0.1
Kanoya JMSDF AB	12	11.9	0.0	11.9	0.0
Futenma MCAS	6	3.5	0.0	3.4	0.1
Hamamatsu JASDF AB	5	0.9	0.0	0.6	0.2
Nyuutabaru JASDF AB	5	2.5	0.3	2.1	0.1
Tsuiki JASDF AB	5	2.3	0.4	1.7	0.2
Hyakuri JASDF AB	4	0.6	0.0	0.5	0.1

Tables A3e and A3f present our full results by day and by base for our fifth set of results: Dispersed to 24 Bases but with low PLA missile accuracy due to jamming and a higher U.S. ballistic missile defense intercept rate (see Figure 2 in the article). Here we continue to assume their SRBMs and MRBMs have a CEP of 45 meters rather than our baseline of 20 meters. We assume their cruise missiles have a CEP of 45 meters rather than our baseline of 10 meters. And we assume that ballistic missiles are intercepted 60% of the time rather than our baseline of 30%.

Table A3e: Full Results by Day, Dispersed to 24 Bases Scenario, Low PLA Missile Accuracy & High U.S. Ballistic Missile Defense Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	34.2	1.1	32.4	0.7	5.9	144.0	95.6
2	27.5	1.1	25.7	0.7	5.8	144.0	95.9
3	22.3	1.0	20.7	0.7	5.8	144.0	96.3
4	18.6	0.8	17.1	0.7	5.8	144.0	96.6
5	15.6	0.6	14.3	0.7	5.8	144.0	96.9
6	13.2	0.3	12.2	0.7	5.7	144.0	97.3
7	11.4	0.0	10.7	0.7	5.7	144.0	97.6
8	10.3	0.0	9.6	0.7	5.7	144.0	98.0
9	9.0	0.0	8.3	0.7	5.6	144.0	98.3
10	7.5	0.0	6.8	0.7	5.6	144.0	98.6
11	5.5	0.0	4.8	0.7	5.6	141.0	96.2
12	3.8	0.0	3.1	0.7	5.5	136.8	92.8
13	3.3	0.0	2.6	0.7	5.5	133.4	90.0
14	3.0	0.0	2.4	0.7	5.5	130.5	87.7
15	2.6	0.0	1.9	0.7	5.5	127.6	85.3
16	2.3	0.0	1.6	0.7	5.4	125.2	83.5
17	1.2	0.0	0.5	0.7	5.4	123.3	82.0
18	1.2	0.0	0.5	0.7	5.4	122.1	81.3
19	1.0	0.0	0.3	0.7	5.4	121.0	80.5
20	0.7	0.0	0.0	0.7	5.3	120.4	80.3
21	0.7	0.0	0.0	0.7	5.3	119.7	80.0
22	0.7	0.0	0.0	0.7	5.3	119.0	79.6
23	0.7	0.0	0.0	0.7	5.3	118.4	79.3
24	0.7	0.0	0.0	0.7	5.2	117.7	79.0
25	0.7	0.0	0.0	0.7	5.2	117.0	78.7
26	0.7	0.0	0.0	0.7	5.2	116.7	78.6
27	0.7	0.0	0.0	0.7	5.2	116.0	78.3
28	0.7	0.0	0.0	0.7	5.1	115.3	78.0
29	0.7	0.0	0.0	0.7	5.1	114.6	77.6
30	0.7	0.0	0.0	0.7	5.1	114.0	77.3
Total	**200.9**	**5.0**	**175.3**	**20.5**	**164.0**	**3,889.6**	**2,617.1**

Table A3f: Full Results by Base, Dispersed to 24 Bases Scenario, Low PLA Missile Accuracy & High U.S. Ballistic Missile Defense Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	46	18.5	0.0	12.9	5.6
Kadena AB	85	45.2	1.3	36.9	7.0
Chitose JASDF AB	35	10.1	0.6	7.2	2.3
Yokota AB	34	6.0	0.0	4.7	1.3
Misawa AB	75	47.4	1.8	44.6	0.9
Komatsu JASDF AB	14	2.1	0.6	0.9	0.6
Guam International	13	3.8	0.0	3.4	0.4
Clark AB	27	16.0	0.0	16.0	0.0
Villamor PAF AB	14	6.0	0.0	5.7	0.3
Cesar Basa PAF AB	5	1.9	0.2	1.5	0.2
Komaki JASDF AB	12	2.5	0.0	2.2	0.3
Naha JASDF AB	15	6.4	0.1	5.9	0.4
Atsugi JMSDF AB	8	1.0	0.0	0.7	0.3
Iwakuni MCAS	12	10.0	0.0	10.0	0.0
Miho JASDF AB	5	3.3	0.0	3.3	0.1
Iruma JASDF AB	5	0.6	0.0	0.5	0.1
Gifu JASDF AB	4	1.0	0.0	0.9	0.1
Saipan International	4	1.0	0.0	1.0	0.1
Kanoya JMSDF AB	12	11.2	0.0	11.2	0.0
Futenma MCAS	6	2.4	0.0	2.3	0.1
Hamamatsu JASDF AB	5	0.8	0.0	0.6	0.2
Nyuutabaru JASDF AB	5	1.6	0.2	1.3	0.1
Tsuiki JASDF AB	5	1.6	0.2	1.2	0.1
Hyakuri JASDF AB	4	0.5	0.0	0.5	0.1

Tables A4a and A4b present our full results by day and by base for our sixth set of results: Agile Combat Employment (ACE) with no U.S. degradation of China's intelligence, surveillance, and reconnaissance (ISR) capabilities (see Figure 3 in the article).

Table A4a: Full Results by Day, Agile Combat Employment, No ISR Degradation Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	98.5	5.7	92.1	0.7	5.9	144.0	95.6
2	63.8	5.1	58.0	0.7	5.8	144.0	95.9
3	45.8	4.3	40.9	0.7	5.8	118.6	73.4
4	35.9	3.7	31.4	0.7	5.8	88.0	46.2
5	29.0	3.2	25.1	0.7	5.8	62.4	23.5
6	23.4	2.3	20.4	0.7	5.7	44.1	7.3
7	19.3	1.9	16.7	0.7	5.7	29.6	0.0
8	15.6	1.9	12.2	1.5	5.1	17.4	0.0
9	13.6	1.5	10.7	1.4	5.1	14.6	0.0
10	11.8	0.9	9.5	1.4	5.1	13.2	0.0
11	6.5	0.7	4.5	1.3	5.0	11.9	0.0
12	3.8	0.2	2.2	1.3	5.0	10.7	0.0
13	1.8	0.0	0.8	1.0	3.9	9.7	0.0
14	1.6	0.0	0.6	1.0	3.9	9.0	0.0
15	1.5	0.0	0.5	1.0	3.9	8.4	0.0
16	1.4	0.0	0.4	1.0	3.9	7.7	0.0
17	1.3	0.0	0.3	1.0	3.8	7.0	0.0
18	1.2	0.0	0.3	1.0	3.8	6.4	0.0
19	0.9	0.0	0.2	0.7	2.7	5.7	0.0
20	0.8	0.0	0.1	0.7	2.7	5.3	0.0
21	0.7	0.0	0.0	0.7	2.7	4.8	0.0
22	0.7	0.0	0.0	0.7	2.7	4.4	0.0
23	0.7	0.0	0.0	0.7	2.7	3.9	0.0
24	0.7	0.0	0.0	0.7	2.6	3.5	0.0
25	0.7	0.0	0.0	0.7	2.6	3.1	0.0
26	0.7	0.0	0.0	0.7	2.6	2.6	0.0
27	0.7	0.0	0.0	0.7	2.6	2.2	0.0
28	0.2	0.0	0.0	0.2	2.4	1.7	0.0
29	0.2	0.0	0.0	0.2	2.4	1.7	0.0
30	0.2	0.0	0.0	0.2	2.4	1.6	0.0
Total	**383.2**	**31.5**	**326.9**	**24.7**	**120.2**	**787.1**	**341.9**

Table A4b: Full Results by Base, Agile Combat Employment, No ISR Degradation Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Misawa AB	52	45.1	19.9	23.8	1.4
Chitose JASDF AB	59	49.2	7.0	41.1	1.1
Andersen AB	91	77.8	0.0	76.0	1.8
Clark AB	63	61.9	0.0	61.8	0.1
Guam International	26	22.2	0.0	19.8	2.4
Komaki JASDF AB	31	14.7	0.0	13.4	1.3
Atsugi JMSDF AB	18	9.9	0.0	4.9	5.0
Kanoya JMSDF AB	21	20.8	0.0	20.8	0.0
Miho JASDF AB	19	19.2	0.0	19.2	0.0
Hamamatsu JASDF AB	10	6.9	0.0	3.9	3.0
Hyakuri JASDF AB	9	6.6	0.0	4.4	2.2
Saipan International	4	3.5	0.0	1.1	2.4
Nyuutabaru JASDF AB	4	3.2	1.2	0.6	1.3
Iwo Jima JASDF AB	12	12.0	0.0	12.0	0.0
Cesar Basa PAF AB	4	3.2	1.4	0.4	1.4
Tsuiki JASDF AB	4	3.1	2.0	0.0	1.0
Edwin Andrews PAF AB	12	12.0	0.0	12.0	0.0
Rota International	4	4.0	0.0	3.8	0.2
Tinian International (West AF)	4	4.0	0.0	3.9	0.1
Naval Station Ernesto Ogbinar	4	4.0	0.0	4.0	0.0

Tables A4c and A4d present our full results by day and by base for our seventh set of results: ACE with moderate U.S. degradation of China's ISR capabilities (see Figure 3 in the article).

Table A4c: Full Results by Day, Agile Combat Employment, Moderate ISR Degradation Scenario

Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	81.2	5.7	74.7	0.7	5.9	144.0	95.6
2	56.1	5.1	50.3	0.7	5.8	144.0	95.9
3	41.4	4.1	36.7	0.7	5.8	134.3	87.5
4	32.9	3.3	28.8	0.7	5.8	108.1	64.3
5	26.9	2.7	23.5	0.7	5.8	85.7	44.5
6	22.2	2.0	19.6	0.7	5.7	69.6	30.4
7	17.4	0.2	16.5	0.7	5.7	56.6	19.0
8	14.8	0.2	13.9	0.7	5.7	46.2	10.0
9	12.1	0.2	11.2	0.7	5.6	37.1	2.1
10	10.8	0.2	9.9	0.7	5.6	29.5	0.0
11	6.8	0.1	5.6	1.2	5.2	22.7	0.0
12	4.4	0.0	2.8	1.5	5.0	18.6	0.0
13	3.7	0.0	2.2	1.5	5.0	16.1	0.0
14	3.2	0.0	1.7	1.5	5.0	14.7	0.0
15	2.7	0.0	1.2	1.5	4.9	13.6	0.0
16	2.2	0.0	0.7	1.5	4.9	12.6	0.0
17	2.0	0.0	0.5	1.5	4.9	11.6	0.0
18	1.9	0.0	0.4	1.5	4.9	10.6	0.0
19	1.2	0.0	0.0	1.2	3.8	9.6	0.0
20	1.2	0.0	0.0	1.2	3.7	8.9	0.0
21	1.2	0.0	0.0	1.2	3.7	8.3	0.0
22	1.2	0.0	0.0	1.2	3.7	7.6	0.0
23	1.2	0.0	0.0	1.2	3.7	6.9	0.0
24	1.2	0.0	0.0	1.2	3.7	6.2	0.0
25	0.9	0.0	0.0	0.9	2.6	5.5	0.0
26	0.9	0.0	0.0	0.9	2.5	5.1	0.0
27	0.9	0.0	0.0	0.9	2.5	4.6	0.0
28	0.9	0.0	0.0	0.9	2.5	4.2	0.0
29	0.9	0.0	0.0	0.9	2.5	3.7	0.0
30	0.9	0.0	0.0	0.9	2.5	3.3	0.0
Total	**354.9**	**23.8**	**300.2**	**30.9**	**134.4**	**1,049.3**	**449.1**

Table A4d: Full Results by Base, Agile Combat Employment, Moderate ISR Degradation Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Misawa AB	52	38.1	14.2	21.8	2.2
Chitose JASDF AB	59	43.2	4.9	35.8	2.6
Andersen AB	91	71.7	0.0	68.4	3.3
Clark AB	63	60.5	0.0	60.4	0.1
Guam International	26	20.2	0.0	16.7	3.5
Komaki JASDF AB	31	12.5	0.0	10.7	1.8
Atsugi JMSDF AB	18	9.1	0.0	4.1	5.0
Kanoya JMSDF AB	21	20.8	0.0	20.8	0.0
Miho JASDF AB	19	19.2	0.0	19.2	0.0
Hamamatsu JASDF AB	10	6.0	0.0	2.7	3.3
Hyakuri JASDF AB	9	5.4	0.0	2.5	2.9
Saipan International	4	3.3	0.0	1.1	2.3
Nyuutabaru JASDF AB	4	3.1	1.3	0.3	1.4
Iwo Jima JASDF AB	12	11.9	0.0	11.9	0.0
Cesar Basa PAF AB	4	3.1	1.4	0.4	1.3
Tsuiki JASDF AB	4	3.0	2.1	0.0	1.0
Edwin Andrews PAF AB	12	11.9	0.0	11.9	0.0
Rota International	4	3.9	0.0	3.6	0.3
Tinian International (West AF)	4	4.0	0.0	3.8	0.1
Naval Station Ernesto Ogbinar	4	4.0	0.0	4.0	0.0

Tables A4e and A4f present our full results by day and by base for our eighth set of results: ACE with full U.S. degradation of China's ISR capabilities (see Figure 3 in the article).

Table A4e: Full Results by Day, Agile Combat Employment, Full ISR Degradation Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	63.4	5.7	57.0	0.7	5.9	144.0	95.6
2	47.7	5.0	42.0	0.7	5.8	144.0	95.9
3	37.4	3.7	33.1	0.7	5.8	144.0	96.3
4	28.5	0.9	26.9	0.7	5.8	123.7	78.3
5	23.4	0.4	22.3	0.7	5.8	106.0	62.8
6	19.6	0.3	18.6	0.7	5.7	94.0	52.3
7	16.7	0.3	15.7	0.7	5.7	84.1	43.7
8	14.5	0.2	13.6	0.7	5.7	75.1	36.0
9	12.7	0.2	11.9	0.7	5.6	66.9	28.9
10	9.9	0.1	9.1	0.7	5.6	59.4	22.5
11	5.5	0.0	4.8	0.7	5.6	53.5	17.6
12	2.2	0.0	1.5	0.7	5.5	50.4	15.0
13	1.2	0.0	0.5	0.7	5.5	49.1	14.2
14	1.0	0.0	0.3	0.7	5.5	48.6	13.9
15	1.0	0.0	0.3	0.7	5.5	47.9	13.6
16	1.0	0.0	0.3	0.7	5.4	47.2	13.3
17	0.7	0.0	0.0	0.7	5.4	46.8	13.2
18	0.7	0.0	0.0	0.7	5.4	46.3	13.0
19	0.7	0.0	0.0	0.7	5.4	45.7	12.8
20	0.7	0.0	0.0	0.7	5.3	45.2	12.6
21	0.7	0.0	0.0	0.7	5.3	44.7	12.4
22	0.7	0.0	0.0	0.7	5.3	44.1	12.2
23	0.7	0.0	0.0	0.7	5.3	43.6	12.0
24	0.7	0.0	0.0	0.7	5.2	43.0	11.8
25	0.7	0.0	0.0	0.7	5.2	42.5	11.6
26	0.7	0.0	0.0	0.7	5.2	41.9	11.4
27	0.7	0.0	0.0	0.7	5.2	41.4	11.2
28	0.7	0.0	0.0	0.7	5.1	40.9	11.0
29	0.7	0.0	0.0	0.7	5.1	40.3	10.8
30	0.7	0.0	0.0	0.7	5.1	39.8	10.6
Total	**295.1**	**16.8**	**257.9**	**20.5**	**164.0**	**1,944.1**	**866.2**

Table A4f: Full Results by Base, Agile Combat Employment, Full ISR Degradation Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Misawa AB	52	31.0	9.2	17.6	4.2
Chitose JASDF AB	59	36.5	3.3	28.7	4.5
Andersen AB	91	59.2	0.0	53.3	5.9
Clark AB	63	56.0	0.0	55.9	0.1
Guam International	26	15.2	0.0	13.6	1.6
Komaki JASDF AB	31	9.1	0.0	7.7	1.4
Atsugi JMSDF AB	18	3.9	0.0	2.7	1.3
Kanoya JMSDF AB	21	20.4	0.0	20.4	0.0
Miho JASDF AB	19	19.1	0.0	19.1	0.0
Hamamatsu JASDF AB	10	2.7	0.0	2.0	0.6
Hyakuri JASDF AB	9	2.3	0.0	1.8	0.5
Saipan International	4	0.6	0.0	0.6	0.0
Nyuutabaru JASDF AB	4	1.6	1.1	0.3	0.1
Iwo Jima JASDF AB	12	11.4	0.0	11.4	0.0
Cesar Basa PAF AB	4	1.7	1.3	0.2	0.1
Tsuiki JASDF AB	4	2.0	1.9	0.0	0.1
Edwin Andrews PAF AB	12	11.7	0.0	11.7	0.0
Rota International	4	3.3	0.0	3.3	0.0
Tinian International (West AF)	4	3.5	0.0	3.5	0.0
Naval Station Ernesto Ogbinar	4	4.0	0.0	4.0	0.0

Tables A5a and A5b present our full results by day and by base for our ninth set of results: Dispersed to 24 Bases + 300 hardened aircraft shelters (HAS) (see Figure 4 in the article).

Table A5a: Full Results by Day, Dispersed to 24 Bases + 300 HAS Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	60.3	55.1	4.6	0.7	5.9	144.0	95.6
2	48.1	42.9	4.6	0.7	5.8	144.0	95.9
3	38.4	33.7	4.0	0.7	5.8	144.0	96.3
4	26.9	23.5	2.8	0.7	5.8	135.9	89.3
5	9.4	6.5	2.2	0.7	5.8	115.2	71.0
6	2.5	0.0	1.8	0.7	5.7	109.0	65.8
7	2.2	0.0	1.6	0.7	5.7	107.0	64.4
8	2.2	0.0	1.5	0.7	5.7	105.1	63.0
9	1.9	0.0	1.2	0.7	5.6	103.6	61.9
10	1.8	0.0	1.1	0.7	5.6	101.8	60.6
11	0.9	0.0	0.2	0.7	5.6	100.4	59.7
12	0.9	0.0	0.2	0.7	5.5	99.5	59.2
13	0.9	0.0	0.2	0.7	5.5	98.6	58.7
14	0.9	0.0	0.2	0.7	5.5	97.7	58.2
15	0.8	0.0	0.2	0.7	5.5	97.0	57.8
16	0.7	0.0	0.0	0.7	5.4	96.3	57.4
17	0.7	0.0	0.0	0.7	5.4	95.6	57.1
18	0.7	0.0	0.0	0.7	5.4	94.9	56.7
19	0.7	0.0	0.0	0.7	5.4	94.3	56.5
20	0.7	0.0	0.0	0.7	5.3	93.6	56.2
21	0.7	0.0	0.0	0.7	5.3	92.9	55.8
22	0.7	0.0	0.0	0.7	5.3	92.3	55.5
23	0.7	0.0	0.0	0.7	5.3	91.6	55.2
24	0.7	0.0	0.0	0.7	5.2	90.9	54.9
25	0.7	0.0	0.0	0.7	5.2	90.2	54.5
26	0.7	0.0	0.0	0.7	5.2	89.5	54.2
27	0.7	0.0	0.0	0.7	5.2	88.9	53.9
28	0.7	0.0	0.0	0.7	5.1	88.2	53.6
29	0.7	0.0	0.0	0.7	5.1	87.5	53.2
30	0.7	0.0	0.0	0.7	5.1	86.8	52.9
Total	**208.3**	**161.7**	**26.2**	**20.5**	**164.0**	**3,076.1**	**1,885.0**

Table A5b: Full Results by Base, Dispersed to 24 Bases + 300 HAS Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	52	28.4	15.8	7.8	4.8
Kadena AB	56	26.3	20.6	3.2	2.4
Chitose JASDF AB	40	14.4	9.8	1.3	3.4
Yokota AB	25	9.6	7.5	1.0	1.1
Misawa AB	33	15.5	12.5	1.3	1.7
Komatsu JASDF AB	13	5.2	3.4	0.1	1.8
Guam International	20	8.3	6.7	0.7	0.9
Clark AB	29	15.8	14.5	1.2	0.0
Villamor PAF AB	11	5.8	3.3	2.3	0.2
Cesar Basa PAF AB	7	3.7	3.1	0.4	0.2
Komaki JASDF AB	14	4.7	4.1	0.0	0.5
Naha JASDF AB	14	5.0	4.4	0.2	0.5
Atsugi JMSDF AB	8	2.9	2.4	0.3	0.2
Iwakuni MCAS	21	12.7	10.5	2.2	0.0
Miho JASDF AB	7	3.5	3.0	0.3	0.2
Iruma JASDF AB	7	2.6	2.2	0.1	0.2
Gifu JASDF AB	7	2.4	2.1	0.1	0.3
Saipan International	13	5.9	4.5	0.9	0.5
Kanoya JMSDF AB	26	13.3	12.4	0.8	0.1
Futenma MCAS	19	10.6	10.0	0.1	0.5
Hamamatsu JASDF AB	7	2.8	2.4	0.1	0.2
Nyuutabaru JASDF AB	7	2.8	2.1	0.4	0.3
Tsuiki JASDF AB	7	3.5	2.2	1.1	0.2
Hyakuri JASDF AB	7	2.7	2.2	0.3	0.2

Tables A5c and A5d present our full results by day and by base for our tenth set of results: Dispersed to 24 Bases + 300 HAS and with enhanced U.S. guidance jamming capabilities that results in lower PLA missile accuracy (see Figure 4 in the article). Here we assume the PLA's SRBMs and MRBMs have a CEP of 45 meters rather than our baseline of 20 meters. We also assume that their cruise missiles have a CEP of 45 meters rather than our baseline of 10 meters.

Table A5c: Full Results by Day, Dispersed to 24 Bases + 300 HAS + Low PLA Missile Accuracy Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	17.1	12.0	4.4	0.7	5.9	144.0	95.6
2	15.0	10.7	3.6	0.7	5.8	144.0	95.9
3	11.4	8.0	2.7	0.7	5.8	144.0	96.3
4	3.9	1.3	1.8	0.7	5.8	144.0	96.6
5	2.1	0.0	1.4	0.7	5.8	144.0	96.9
6	1.8	0.0	1.2	0.7	5.7	144.0	97.3
7	1.7	0.0	1.0	0.7	5.7	144.0	97.6
8	1.7	0.0	1.0	0.7	5.7	144.0	98.0
9	1.5	0.0	0.8	0.7	5.6	144.0	98.3
10	1.4	0.0	0.7	0.7	5.6	144.0	98.6
11	0.8	0.0	0.2	0.7	5.6	144.0	99.0
12	0.8	0.0	0.2	0.7	5.5	144.0	99.3
13	0.8	0.0	0.2	0.7	5.5	144.0	99.5
14	0.8	0.0	0.2	0.7	5.5	144.0	99.8
15	0.8	0.0	0.1	0.7	5.5	144.0	100.1
16	0.7	0.0	0.0	0.7	5.4	144.0	100.4
17	0.7	0.0	0.0	0.7	5.4	144.0	100.7
18	0.7	0.0	0.0	0.7	5.4	144.0	101.0
19	0.7	0.0	0.0	0.7	5.4	144.0	101.2
20	0.7	0.0	0.0	0.7	5.3	144.0	101.5
21	0.7	0.0	0.0	0.7	5.3	144.0	101.8
22	0.7	0.0	0.0	0.7	5.3	144.0	102.1
23	0.7	0.0	0.0	0.7	5.3	144.0	102.4
24	0.7	0.0	0.0	0.7	5.2	144.0	102.7
25	0.7	0.0	0.0	0.7	5.2	144.0	102.9
26	0.7	0.0	0.0	0.7	5.2	144.0	103.2
27	0.7	0.0	0.0	0.7	5.2	144.0	103.5
28	0.7	0.0	0.0	0.7	5.1	144.0	103.8
29	0.7	0.0	0.0	0.7	5.1	144.0	104.1
30	0.7	0.0	0.0	0.7	5.1	144.0	104.4
Total	**72.0**	**32.1**	**19.5**	**20.5**	**164.0**	**4,320.0**	**3,004.5**

Table A5d: Full Results by Base, Dispersed to 24 Bases + 300 HAS + Low PLA Missile Accuracy Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	52	17.3	3.6	5.3	8.3
Kadena AB	56	13.1	4.4	2.6	6.0
Chitose JASDF AB	40	3.4	1.3	0.9	1.2
Yokota AB	25	2.3	1.2	0.8	0.3
Misawa AB	33	3.8	2.5	0.8	0.5
Komatsu JASDF AB	13	0.7	0.3	0.1	0.3
Guam International	20	2.5	1.5	0.4	0.5
Clark AB	29	4.4	3.3	1.1	0.0
Villamor PAF AB	11	2.8	0.8	1.9	0.2
Cesar Basa PAF AB	7	1.2	0.7	0.3	0.2
Komaki JASDF AB	14	0.8	0.4	0.0	0.3
Naha JASDF AB	14	1.3	0.8	0.1	0.3
Atsugi JMSDF AB	8	0.8	0.4	0.3	0.2
Iwakuni MCAS	21	4.1	2.4	1.6	0.2
Miho JASDF AB	7	1.1	0.6	0.3	0.2
Iruma JASDF AB	7	0.6	0.4	0.1	0.2
Gifu JASDF AB	7	0.4	0.2	0.1	0.2
Saipan International	13	1.9	1.1	0.5	0.3
Kanoya JMSDF AB	26	3.0	2.4	0.6	0.1
Futenma MCAS	19	2.6	2.1	0.1	0.5
Hamamatsu JASDF AB	7	0.6	0.4	0.1	0.2
Nyuutabaru JASDF AB	7	1.0	0.5	0.4	0.2
Tsuiki JASDF AB	7	1.5	0.5	0.9	0.2
Hyakuri JASDF AB	7	0.7	0.4	0.2	0.2

Tables A5e and A5f present our full results by day and by base for our eleventh and final set of results: Dispersed to 24 Bases + 300 HAS, increased guidance jamming capabilities, and increased U.S. ballistic missile defense capabilities (see Figures 4 and 5 in the article). Here we continue to assume their SRBMs & MRBMs have a CEP of 45 meters rather than our baseline of 20 meters. We assume their cruise missiles have a CEP of 45 meters rather than our baseline of 10 meters. And we assume that ballistic missiles are intercepted 60% of the time rather than our baseline of 30%.

Table A5e: Full Results by Day, Dispersed to 24 Bases + 300 HAS + Low PLA Missile Accuracy + High U.S. BMD Scenario							
Days	Total U.S. losses	U.S. HAS losses	U.S. parking losses	U.S. air-to-air losses	PLA aircraft losses	U.S. OCA sweep sorties	U.S. strike sorties
1	10.3	7.0	2.6	0.7	5.9	144.0	95.6
2	9.3	6.5	2.1	0.7	5.8	144.0	95.9
3	7.7	5.3	1.7	0.7	5.8	144.0	96.3
4	2.7	0.9	1.1	0.7	5.8	144.0	96.6
5	1.6	0.0	0.9	0.7	5.8	144.0	96.9
6	1.4	0.0	0.8	0.7	5.7	144.0	97.3
7	1.4	0.0	0.7	0.7	5.7	144.0	97.6
8	1.3	0.0	0.7	0.7	5.7	144.0	98.0
9	1.2	0.0	0.5	0.7	5.6	144.0	98.3
10	1.2	0.0	0.5	0.7	5.6	144.0	98.6
11	0.8	0.0	0.1	0.7	5.6	144.0	99.0
12	0.8	0.0	0.1	0.7	5.5	144.0	99.3
13	0.8	0.0	0.1	0.7	5.5	144.0	99.5
14	0.8	0.0	0.1	0.7	5.5	144.0	99.8
15	0.8	0.0	0.1	0.7	5.5	144.0	100.1
16	0.7	0.0	0.0	0.7	5.4	144.0	100.4
17	0.7	0.0	0.0	0.7	5.4	144.0	100.7
18	0.7	0.0	0.0	0.7	5.4	144.0	101.0
19	0.7	0.0	0.0	0.7	5.4	144.0	101.2
20	0.7	0.0	0.0	0.7	5.3	144.0	101.5
21	0.7	0.0	0.0	0.7	5.3	144.0	101.8
22	0.7	0.0	0.0	0.7	5.3	144.0	102.1
23	0.7	0.0	0.0	0.7	5.3	144.0	102.4
24	0.7	0.0	0.0	0.7	5.2	144.0	102.7
25	0.7	0.0	0.0	0.7	5.2	144.0	102.9
26	0.7	0.0	0.0	0.7	5.2	144.0	103.2
27	0.7	0.0	0.0	0.7	5.2	144.0	103.5
28	0.7	0.0	0.0	0.7	5.1	144.0	103.8
29	0.7	0.0	0.0	0.7	5.1	144.0	104.1
30	0.7	0.0	0.0	0.7	5.1	144.0	104.4
Total	**52.4**	**19.7**	**12.2**	**20.5**	**164.0**	**4,320.0**	**3,004.5**

Table A5f: Full Results by Base, Dispersed to 24 Bases + 300 HAS + Low PLA Missile Accuracy + High U.S. BMD Scenario					
	Total Deployed	Total Lost	HAS Loss	Parking Loss	Air-to-Air Loss
Andersen AB	52	14.5	2.1	3.2	9.2
Kadena AB	56	10.2	2.7	1.6	5.9
Chitose JASDF AB	40	2.1	0.9	0.5	0.6
Yokota AB	25	1.7	0.8	0.5	0.3
Misawa AB	33	2.5	1.5	0.5	0.5
Komatsu JASDF AB	13	0.6	0.3	0.1	0.3
Guam International	20	1.6	0.9	0.2	0.5
Clark AB	29	2.5	1.9	0.6	0.0
Villamor PAF AB	11	1.8	0.4	1.2	0.2
Cesar Basa PAF AB	7	0.8	0.4	0.2	0.2
Komaki JASDF AB	14	0.8	0.4	0.0	0.3
Naha JASDF AB	14	0.9	0.5	0.1	0.3
Atsugi JMSDF AB	8	0.6	0.3	0.2	0.2
Iwakuni MCAS	21	2.6	1.3	1.0	0.2
Miho JASDF AB	7	0.7	0.4	0.2	0.2
Iruma JASDF AB	7	0.5	0.3	0.1	0.2
Gifu JASDF AB	7	0.4	0.2	0.1	0.2
Saipan International	13	1.2	0.6	0.3	0.3
Kanoya JMSDF AB	26	1.9	1.5	0.4	0.1
Futenma MCAS	19	1.8	1.3	0.0	0.5
Hamamatsu JASDF AB	7	0.5	0.3	0.1	0.2
Nyuutabaru JASDF AB	7	0.6	0.3	0.2	0.2
Tsuiki JASDF AB	7	1.1	0.3	0.6	0.2
Hyakuri JASDF AB	7	0.5	0.3	0.1	0.2

Aerial Refueling Model Results

Table A6 presents the results of the aerial refueling analysis by scenario. Full details for how this analysis was conducted are in Appendix F. As noted in Appendix D, we assume that the U.S. makes half of its global tanker fleet available for the operation, and that the tankers are 70 percent mechanically ready. As Table A6 makes clear, we also assume that tanker operations are concentrated at two Australian air bases for the operation: Royal Australian Air Force (RAAF) Darwin and RAAF Tindal. Note that the model only accounts for aerial refueling, not ground refueling, which, for the purpose of the analysis, we assume to be effectively unlimited.

Table A6: Aerial Refueling Model Results by Scenario													
	RAAF Darwin				RAAF Tindal				*Peak Daily Fuel Demand (kg)*	*Daily Fuel Supply (kg)*	*Supply / Demand*	Available Tankers Remaining	
	KC-135R/T		*KC-46A*		*KC-135R/T*		*KC-46A*						
Scenario	*O1*	*O2*	*O1*	*O2*	*O1*	*O2*	*O1*	*O2*				*KC-135R/T*	*KC-46A*
US 6 Bases	26	10	4	4	27	10	4	4	3,370,343	3,459,350	102.6%	57	15
Dispersed to 15 Bases	27	15	6	5	27	14	6	5	3,934,512	4,005,440	101.8%	47	9
Dispersed to 24 Bases	28	13	5	5	28	13	5	5	3,830,363	3,896,820	101.7%	48	11
Agile Combat Employment	24	13	4	4	23	13	4	4	3,338,478	3,389,421	101.5%	57	15
Dispersed to 24 + 300 HAS	28	11	6	4	27	10	6	4	3,650,145	3,699,055	101.3%	54	11

B) Sensitivity Analysis & Simulation

This section presents the full results of the sensitivity analysis and simulation presented in the article. To conduct the sensitivity analysis, we set all of our input variables to their baseline values for the following scenario: Dispersed to 24 Bases + 300 hardened aircraft shelters (HAS). We then varied the input values for 36 variables—one at a time—setting them to their lowest and highest plausible values and recording the results. Table B1, below, presents the results of the sensitivity analysis.

Table B1: Sensitivity Analysis on Dispersed to 24 Bases + 300 HAS Scenario						
Variable	**Baseline value**	**Low value**	**High value**	**Baseline result**	**Low result**	**High result**
U.S. Sortie Generation Model & Air Base Variables						
Aircraft used for other missions	50	0	100	208	196 (-6%)	221 (+6%)
Loss rate on aircraft used for other missions (%)	0.5%	0.25%	0.75%		201 (-3%)	216 (+4%)
DCA aircraft required	12	6	18		191 (-8%)	236 (+13%)
Ballistic Missile Defense intercept rate (%)	30%	15%	45%		241 (+16%)	175 (-16%)
Share of allied HAS available (%)	50%	25%	75%		222 (+7%)	196 (-6%)
HAS fill rate (%)	100%	75%	—		194 (-7%)	—
O1 distance from OCA target area (km)	593	393[a]	—		207 (-0%)	—
U.S. fighter aircraft cruising speed (km/h)	915	900	930		208 (-0%)	208 (-0%)
Base operational delay after missile attacks (mins)	30	0	60		208 (0%)	208 (+0%)
PLA Missile Attack Model Variables						
PLA missiles held in reserve (%)	33%	20%	46%	208	233 (+12%)	168 (-19%)
Days PLA missiles allocated over	10	5	15		206 (-1%)	208 (-0%)
Areas PLA missiles are deployed to cover[b]	3	2	4		202 (-3%)	208 (0%)
Ballistic and cruise missile accuracy (m CEP)	20 & 10	10 & 5	30 & 15		332 (+60%)	127 (-39%)
Missiles allocated to HAS	1,170	870	1,470		190 (-9%)	204 (-2%)
DF-26 IRBM range (km)	4,000	3,000	5,000		194 (-7%)	206 (-1%)
PLA missile launcher operating range (km)	100	50	150		202 (-3%)	216 (+4%)
PLA battle damage assessment blocked	No	—	Yes		—	176 (-15%)
Air-to-Air Combat Model Variables						
Air-to-air combat mission (OCA vs. DCA)	OCA	—	DCA	208	—	227 (+9%)
U.S. OCA sweeps per day	2	1	3		206 (-1%)	207 (-0%)
Size of U.S. OCA sweep	72	62	82		208 (0%)	208 (0%)
Air-to-air maximum ratio (U.S.:PLA)	2	1	3		208 (0%)	208 (0%)
Share of patrols that successfully engage (%)	50%	25%	75%		206 (-1%)	211 (+1%)
PLA 4th generation aircraft	440	340	540		208 (-0%)	209 (+0%)
PLA 5th generation aircraft	160	120	200		208 (0%)	208 (0%)
PLA CAP locations	3	1	—		216 (+4%)	—
PLA sortie rate	1.0	0.5	1.5		204 (-2%)	210 (+1%)
Share of PLA aircraft that seek to engage (%)	80%	60%	100%		208 (-0%)	209 (+0%)
U.S. missiles fired per engagement[c]	2-4	-1	+1		208 (0%)	208 (0%)
PLA missiles fired per engagement[c]	1-2	-1	+1		203 (-2%)	214 (+3%)
U.S. air-to-air missile p(hit) (%)[d]	42%-70%	-10%	+10%		208 (0%)	208 (0%)
PLA air-to-air missile p(hit) (%)[d]	30%-50%	-10%	+10%		207 (-0%)	210 (+1%)

U.S. air-to-air missile p(kill|hit) (%)	70%	60%	80%		208 (0%)	208 (0%)
PLA air-to-air missile p(kill|hit) (%)	70%	60%	80%		208 (-0%)	209 (+0%)
U.S. aircraft p(avoid electronic attack) (%)[e]	30%-65%	-10%	+10%		208 (0%)	208 (0%)
PLA aircraft p(avoid electronic attack) (%)[e]	22.5%-65%	-10%	+10%		206 (-1%)	210 (+1%)
Taiwan air defense intercept rate (%)	0.5%	0%	1%		208 (0%)	208 (0%)

[a] The coordinates for this alternative refueling point are 22.6996, 124.5856.
[b] At baseline, the PLA covers Japan, the Philippines, and Pacific Island bases. Under 2 (low), we drop the Philippines. Under 4 (high), we add South Korea.
[c] The number of missiles fired depends both on the generation of the aircraft firing the missile and the generation of the aircraft it is facing.
[d] The missile's p(hit) depends both on the generation of the aircraft firing the missile and the generation of the aircraft it is facing.
[e] The aircraft's probability of avoiding electronic attack depends both on the generation of the aircraft firing the missile and the generation of the aircraft it is facing.

We conducted Monte Carlo simulations using Microsoft Excel.[2] Model results were simulated 1,000 times. For the simulation, we used almost all of the same model variables and ranges of input values that were used in the sensitivity analysis. However, because we are interested in the robustness of the final scenario modeled in the paper—dispersed to 24 bases with 300 additional HAS and enhanced guidance jamming and missile defense—we didn't allow the following variables to vary in the analysis: U.S. ballistic missile defense (BMD) intercept rate (fixed at 60%); ballistic and cruise missile accuracy (fixed at 45 meters circular error probable or CEP); and the U.S. air-to-air mission (fixed on offensive counter-air or OCA). Because it was too difficult to randomize, we also didn't include the location of the U.S.'s O1 refueling point—and therefore its distance from the offensive counterair target area (fixed at 593 km). All variables that were included and their value ranges are presented in Table B2, below. The variable ranges were all uniformly distributed. To conduct the simulation, Excel randomly selected values for each of these variables from the defined ranges of values and put them into the model to produce results. Each result was recorded and the process repeated itself 1,000 times.[3] Table B3, below, presents detailed results of the simulation analysis (see also Table 1 in the article).

[2] The supplementary files accompanying the article include a version of the model (.xlsx) that is set up to run the simulations described here.

[3] Simulations were run using the "Data Table" function in Excel. To run the simulations, we first made each of the chosen input parameters (on the "Key Inputs" spreadsheet) uniform statistical distributions using the =RANDBETWEEN() function. So, for instance, the "PLA Missiles in Reserve" input parameter (a percentage) was coded as =RANDBETWEEN(20,46)/100. Once each input parameter was defined as a distribution, the simulations were ready to be run (and could be run one at a time by pressing F9). To record the results of the simulations, we created a new spreadsheet ("Simulation"). With this spreadsheet, starting from Cell B3, we listed numbers 1 to 1,000 downward (ending in Cell B1002). Then, at the top of the spreadsheet, in Cell C2, we input the key output value of interest (U.S. Aircraft Losses) using = and the location of that value ("Key Inputs" sheet, Cell G3). We then highlighted both columns B and C for each of the 1,000 rows (B2:C1002). With all of these cells highlighted, we clicked the "Data" tab and then clicked "What-If Analysis" under the "Forecast" group, and then clicked "Data Table…" in the drop-down menu. Then, in the Data Table dialog box, we left "Row input cell" blank, clicked the box beside "Column input cell," and then clicked a cell on the spreadsheet that wasn't one of the 2,000 highlighted cells. Then we clicked "OK" and a few minutes later,

results were produced. A problem with running simulations with Excel is that there isn't a function that can be used to set a seed, so that the same random variables can be produced with each run of the simulation. This means that our results can't be precisely replicated. Though, with 1,000 runs of the simulation, replicated results should be very close.

Table B2: Simulation Variables and Values for 24 Bases + 300 HAS, Jamming, & BMD		
Variable	**Baseline Model Value**	**Simulation Value Range**
U.S. Sortie Generation Model & Air Base Variables		
Aircraft used for other missions	50	0-100
Loss rate on aircraft used for other missions (%)	0.5%	0.25%-0.75%
DCA aircraft required	12	6-18
Share of allied HAS available (%)	50%	25%-75%
HAS fill rate (%)	100%	75%-100%
U.S. fighter aircraft cruising speed (km/h)	915	900-930
Base operational delay after missile attacks (mins)	30	0-60
PLA Missile Attack Model Variables		
PLA missiles held in reserve (%)	33%	20%-46%
Days PLA missiles allocated over	10	5-15
Areas PLA missiles are deployed to cover[a]	3	2-4
Missiles allocated to HAS	1,170	870-1,470
DF-26 IRBM range (km)	4,000	3,000-5,000
PLA missile launcher operating range (km)	100	50-150
PLA battle damage assessment blocked	NO	NO/YES
Air-to-Air Combat Model Variables		
U.S. OCA sweeps per day	2	1-3
Size of U.S. OCA sweep	72	62-82
Air-to-air maximum ratio (U.S.:PLA)	2	1-3
Share of patrols that successfully engage (%)	50%	25%-75%
PLA 4th generation aircraft	440	340-540
PLA 5th generation aircraft	160	120-200
PLA CAP locations	3	1/3[b]
PLA sortie rate	1.0	0.5-1.5
Share of PLA aircraft that seek to engage (%)	80%	60%-100%
U.S. missiles fired per engagement[c]	2-4	1-5
PLA missiles fired per engagement[c]	1-2	0-3
U.S. air-to-air missile p(hit) (%)[d]	42%-70%	32%-80%
PLA air-to-air missile p(hit) (%)[d]	30%-50%	20%-60%
U.S. air-to-air missile p(kill|hit) (%)	70%	60%-80%
PLA air-to-air missile p(kill|hit) (%)	70%	60%-80%
U.S. aircraft p(avoid electronic attack) (%)[e]	30%-65%	20%-75%
PLA aircraft p(avoid electronic attack) (%)[e]	22.5%-65%	12.5%-75%
Taiwan air defense intercept rate (%)	0.5%	0.0%-1.0%

[a] Here, 2 would be Japan and the Pacific Island bases, 3 adds the Philippines bases, and 4 adds the Korean bases.

[b] Note that this is 1 or 3, not 1 through 3. Given the geography of Taiwan and the Strait, we assume 2 CAP points would serve little purpose.

[c] The number of missiles fired depends both on the generation of the aircraft firing the missile and the generation of the aircraft it is facing.
[d] The missile's p(hit) depends both on the generation of the aircraft firing the missile and the generation of the aircraft it is facing.
[e] The aircraft's probability of avoiding electronic attack depends both on the generation of the aircraft firing the missile and the generation of the aircraft it is facing.

Table B3: Simulation Results, U.S. Aircraft Losses for 24 Bases + 300 HAS, Jamming, & BMD (n=1,000)	
Minimum	15
5th Percentile	28
10th Percentile	33
15th Percentile	37
20th Percentile	40
25th Percentile	44
Baseline	**52**
Median	60
75th Percentile	79
80th Percentile	84
85th Percentile	90
90th Percentile	97
95th Percentile	108
Maximum	169

C) Geography & Bases

Our model allows the user to choose up to 25 bases out of a total of 74 military and civilian airfields in maritime Asia.[4] To define the population of bases, we include:

- all U.S. Air Force bases in the maritime Asia;
- all other U.S. military bases with runways in maritime Asia;[5]
- all U.S. ally air bases in maritime Asia;[6]
- a few, larger civilian airports in Oceania;
- a few northern Australian air bases for tanker aircraft operations.

The presence of an airfield on our list does not presume that such facilities would be available to the U.S. military during a war; instead, it allows analysts to employ that base in a scenario to evaluate its usefulness and potential value in wartime.

Table C1 presents the population of bases in the model, along with some of their relevant characteristics. For allied bases and shared facilities (i.e., those used by both U.S. and allied forces in peacetime), we assume as a baseline that U.S. aircraft would have access to 50% of any hardened aircraft shelters (HAS) at the airfield, if it were used in a war.[7]

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[4] The supplementary files accompanying the article include a Google Earth file (.kml) that maps all relevant locations for the analysis, including all of these air bases.
[5] To be included, a base must have at least one runway that equals or exceeds the minimum operating strip (MOS) length of 1,525 meters for fighter aircraft. See: *Air Force Pamphlet 10-219*, Vol. 4, *Airfield Damage Repair Operations* (Maxwell AFB: United States Air Force, May 2008), pp. 70-71.
[6] U.S. allies include Japan, South Korea, Thailand, and the Philippines. As above, to be counted a base must have at least one runway that meets the minimum operating strip length of 1,525 meters for fighter aircraft.
[7] The 50% assumption accounts for the HAS that would normally be sheltering host nation aircraft. We consider the following bases with HAS to be shared: Misawa Air Base, Kunsan Air Base, and Osan Air Base. Note that we treat Kadena Air Base as a U.S. facility and permit U.S. forces to occupy all the HAS there.

Table C1: U.S. and Allied Air Bases & Relevant Specifications					
Base	**Location (lat., long.)**	**Runways**	**Total Parking Area (m^2)**	**Hardened Aircraft Shelters (HAS)**	**Air Def. Zone**
Australia					
RAAF Curtin	-17.5806064262, 123.828371587	1	265,050	0	14
RAAF Darwin	-12.4143210571, 130.879895268	2	717,900	0	15
RAAF Scherger	-12.6229858749, 142.088300508	1	306,600	0	16
RAAF Tindal	-14.5209453626, 132.377722759	1	1,161,050	0	15
Guam					
Andersen AFB	13.5836717917, 144.929279245	2	2,548,250	0	9
Guam International	13.4853636042, 144.797959355	2	702,500	0	9
Japan (U.S. bases)					
Futenma MCAS	26.2732874765, 127.75759108	1	318,600	0	1
Iwakuni MCAS	34.1460782595, 132.243804103	1	511,150	0	3
Kadena AB	26.3554643058, 127.767689351	2	3,737,800	15	1
Misawa AB	40.702975252, 141.36958768	1	356,400	63	5
Yokota AB	35.7473648032, 139.348741207	1	1,797,800	0	4
Japan					
Ashiya JASDF AB	33.883221217, 130.654620311	1	118,575	0	2
Atsugi JMSDF AB	35.4540639432, 139.450041287	1	456,275	0	4
Chitose JASDF AB	42.7948550162, 141.664758282	4	1,127,500	28	6
Gifu JASDF AB	35.3949062925, 136.870684786	1	193,500	0	4
Hachinohe JMSDF AB	40.55101612, 141.468235468	1	156,975	0	5
Hamamatsu JASDF AB	34.7508248924, 137.703423018	1	240,900	0	4
Hyakuri JASDF AB	36.1815353224, 140.415847583	2	192,600	0	4
Iruma JASDF AB	35.8422062724, 139.409967688	1	251,000	0	4
Iwo Jima JASDF AB	24.7847107427, 141.324142498	1	141,800	0	7
Kanoya JMSDF AB	31.3694543704, 130.835306663	2	339,575	0	2
Kisarazu JGSDF AF	35.3993878732, 139.910439362	1	188,700	0	4
Komaki JASDF AB	35.2560381461, 136.923789277	1	692,625	0	4
Komatsu JASDF AB	36.3931844416, 136.407895044	1	179,625	20	4
Matsushima JASDF AB	38.4038727825, 141.214017368	1	131,625	0	5
Miho JASDF AB	35.4941756435, 133.240326474	1	278,100	0	3
Naha JASDF AB	26.195797057, 127.645867804	1	697,500	4	1
Nyuutabaru JASDF AB	32.0843135634, 131.454022437	2	152,625	4	2
Tsuiki JASDF AB	33.6837498333, 131.040505752	1	108,625	6	2
Korea (U.S. bases)					
Camp Humphrey's AF	36.961293893, 127.031211271	1	281,150	0	8
Kunsan AB	35.9051907604, 126.617820839	1	259,200	83	8
Osan AB	37.0904945236, 127.029583291	2	46,800	79	8
Korea					
Cheongju ROKAF	36.7165380738, 127.49932359	2	487,500	40	8
Daegu ROKAF	35.8937987645, 128.657693483	2	99,975	99	8
Gangneung ROKAF	37.7526300542, 128.944614087	1	36,000	54	8
Gimhae ROKAF	35.1797823611, 128.939101455	2	910,325	0	8

Gwangju ROKAF	35.1265702234, 126.808887442	2	230,750	50	8
Jungwon (Chungju) ROKAF	37.0294063758, 127.885530891	2	122,725	82	8
Mokpo ROKN	34.7584681889, 126.380056467	1	37,775	0	8
Pohang ROKN	35.9875467006, 129.420372113	1	375,650	0	8
Sacheon ROKAF	35.0893236512, 128.070491509	2	228,125	4	8
Seongnam ROKAF	37.4425964877, 127.111950033	2	639,625	13	8
Seosan ROKAF	36.7045627734, 126.48649536	2	142,450	72	8
Suwon ROKAF	37.2387110298, 127.007086284	3	143,450	111	8
Wonju ROKAF	37.4382353649, 127.961842386	1	210,000	58	8
Yecheon ROKAF	36.6307503786, 128.354938747	1	144,550	56	8
Northern Marianas					
Rota International	14.1743841952, 145.241712931	1	43,450	0	9
Saipan International	15.1192195911, 145.729792805	2	164,000	0	9
Tinian International	14.9989617294, 145.619427864	1	33,000	0	9
Palau & Micronesia					
Palau International	7.36731388118, 134.543895405	1	63,100	0	10
Yap International	9.49871928443, 138.082292607	1	21,325	0	10
Philippines					
Antonio Bautista PAF AB	9.74211029326, 118.75876999	1	146,500	0	12
Cesar Basa PAF AB	14.9856618157, 120.493013309	1	122,775	4	11
Clark AB	15.1823126894, 120.556834924	1	1,430,700	0	11
Danilo Atienza PAF AB	14.4949226647, 120.905182495	1	100,500	0	11
Edwin Andrews PAF AB	6.92206031701, 122.061795307	1	100,150	0	13
Lumbia PAFAF	8.41673913488, 124.611560657	1	34,000	0	13
Mactan Benito Ebuen PAF AB	10.3102475213, 123.980504835	1	381,575	0	12
Naval Station Ernesto Ogbinar	16.5976272654, 120.30451835	1	15,000	0	11
Rajah Buayan PAF AS	6.10756187695, 125.235083515	1	11,500	0	13
Villamor PAF AB	14.5095335926, 121.018653573	2	775,600	0	11
Thailand					
Cha-ian Airport	8.46729658353, 99.9566345659	1	18,375	0	20
Chiang Mai Intl Airport	18.7674504342, 98.9640060329	1	207,300	0	17
Don Muang RTAF AB	13.912498343, 100.60622466	2	1,841,600	0	19
Hat Yai Intl Airport	6.93299800294, 100.393005008	1	132,400	0	20
Kamphaeng Saen RTAF AB	14.1006884366, 99.9183369594	1	94,500	0	19
Khok Kathiam RTAF AB	14.8747165262, 100.661119463	1	130,525	0	19
Korat RTAF AB	14.9333282649, 102.079578906	1	297,050	14	18
Phitsanulok Airport	16.7851045785, 100.276487694	1	145,425	0	17
Prachuap Khiri Khan RTAF AB	11.7864942617, 99.7997861674	1	55,125	0	19
Surat Thani RTAF AB	9.13304171607, 99.1347635931	1	332,800	0	20
Takhli RTAF AB	15.2740308878, 100.294759961	1	402,525	0	19
Ubon RTAF AB	15.2512568065, 104.870262656	1	187,775	0	18
U-Tapao Intl Airport	12.678868514, 101.003413885	1	1,129,725	0	19
Note: location, runway, parking area, and hardened aircraft shelter data collected by the authors by visual inspection using Google Earth Pro.					

Defining Scenarios and Basing U.S. Forces

In the article, we present results for five basic scenarios, each of which reflects a particular U.S. deployment strategy. In all scenarios, we assume that the U.S. Air Force will have 450 fighter aircraft at its disposal (see Appendix D for details).

Scenario 1 has U.S. aircraft deployed to six of its main peacetime air bases in Guam and Japan.[8] U.S. aircraft were assigned to the six bases according to the following rules: (1) deploy enough aircraft for a defensive counterair (DCA) mission over the base, starting with 4th generation aircraft, and filling in with 5th generation aircraft, if needed;[9] (2) deploy enough aircraft to fill all available HAS, starting with 5th generation aircraft and filling in with 4th generation aircraft, if needed;[10] (3) deploy all remaining aircraft across the bases in proportion to the size of their parking areas.[11] Table C2 presents the list of bases and the number of aircraft deployed to each base in this scenario.

[8] Because South Korea has not openly agreed to participate in a Taiwan conflict scenario, we do not include U.S. bases there (Osan AB, Kunsan AB) in our analysis. Note that the model includes South Korean facilities in the *population* of bases to permit analysts to explore the potential usefulness of those facilities.
[9] In all scenarios, the number of DCA aircraft required at a given base is estimated using the following rules: (1) the DCA baseline for a given base is 24 aircraft; (2) most bases in Japan only require ½ the normal DCA deployment because of the protection provided by Japan Air Self-Defense Force (JASDF) aircraft; (3) unlike other bases in Japan, those in Okinawa require the full DCA deployment because of their proximity to China; (4) airfields outside of PLAAF fighter range only require ½ of the normal DCA deployment to reflect the reduced air attack threat (which would largely be from cruise missiles). Lastly, following the pattern the United States and Japan created for bases in Japan, we divide the region into various air defense zones, as depicted in Table C1. Only the first base selected in any given zone requires *any* DCA deployment, meaning that one base per zone provides protection to all the others in that zone.
[10] Given that in our analysis we assume a large U.S. deployment (450 aircraft in the baseline deployment), there are far more U.S. 5th generation aircraft in the theater than there are HAS, so in practice all HAS in this scenario are filled with 5th generation aircraft. The model, however, allows the user to deploy different numbers of aircraft to the theater, varying mixes of 4th and 5th generation aircraft, and to build more HAS at these bases. Therefore, it allows for possibilities that there may be more HAS at a given base than there are 5th generation aircraft and it automatically slots 4th generation aircraft into unused shelters.
[11] Deployments are limited by the base's capacity, or "maximum on ground" (MOG).

Table C2: U.S. Six Bases and Aircraft Deployment				
Base	**5th Gen. Aircraft**	**4th Gen. Aircraft**	**DCA Aircraft (4th Gen.)**	**Total**
Andersen AFB	67	32	12	**111**
Kadena AB	103	51	24	**178**
Iwakuni MCAS	10	0	12	**22**
Futenma MCAS	10	4	0	**14**
Misawa AB	35	0	12	**47**
Yokota AB	44	22	12	**78**
Total	**269**	**109**	**72**	**450**

Scenario 2 is Dispersion to 15 Bases. It takes the same number of aircraft as Scenario 1 (450) and disperses them among the best 15 air bases in the collection of bases. We chose the best 15 air bases according to the following priorities: (1) bases with existing HAS; (2) bases with larger parking areas (to reduce density of open-parked aircraft); and (3) bases that are geographically proximate to each other, to increase efficiency of air and missile defense. Aircraft were deployed across the 15 best bases according to the same rules as in scenario 1 (above): starting with the DCA mission (4th gen. aircraft first), then filling HAS (5th gen. aircraft first), and then deploying proportional to parking. Table C3 presents the list of bases and the number of aircraft deployed to each in this scenario.

Table C3: Dispersed to 15, Bases and Aircraft Deployment				
Base	**5th Gen. Aircraft**	**4th Gen. Aircraft**	**DCA Aircraft (4th Gen.)**	**Total**
Andersen AFB	31	14	12	**57**
Kadena AB	61	12	24	**97**
Chitose JASDF AB	27	0	12	**39**
Yokota AB	20	6	12	**38**
Misawa AB	63	0	12	**75**
Komatsu JASDF AB	11	3	0	**14**
Guam International	9	6	0	**15**
Clark AB	8	0	24	**32**
Komaki JASDF AB	8	7	0	**15**
Villamor PAF AB	10	7	0	**17**
Naha JASDF AB	10	7	0	**17**
Atsugi JMSDF AB	5	5	0	**10**
Iwakuni MCAS	0	0	12	**12**
Miho JASDF AB	2	4	0	**6**
Iruma JASDF AB	4	2	0	**6**
Total	**269**	**73**	**108**	**450**

Scenario 3 is Dispersion to 24 Bases. This scenario uses the same number of aircraft (450) as the two previous scenarios and disperses them among the best 24 bases in the region. The best 24 bases were selected using the same priorities as the previous scenario (above): based on the number of HAS, the size of parking areas, and their proximity to each other. Aircraft were then deployed across the 24 best bases according to the same rules as in scenarios 1 and 2 (above): starting with the DCA mission, then filling HAS, and then deploying proportional to parking. Table C4 presents the list of bases and the number of aircraft deployed to each in this scenario.

Table C4: Dispersed to 24, Bases and Aircraft Deployment				
Base	**5th Gen. Aircraft**	**4th Gen. Aircraft**	**DCA Aircraft (4th Gen.)**	**Total**
Andersen AFB	26	8	12	**46**
Kadena AB	53	8	24	**85**
Chitose JASDF AB	13	10	12	**35**
Yokota AB	18	4	12	**34**
Misawa AB	63	0	12	**75**
Komatsu JASDF AB	14	0	0	**14**
Guam International	12	1	0	**13**
Clark AB	3	0	24	**27**
Villamor PAF AB	10	4	0	**14**
Cesar Basa PAF AB	5	0	0	**5**
Komaki JASDF AB	7	5	0	**12**
Naha JASDF AB	13	2	0	**15**
Atsugi JMSDF AB	6	2	0	**8**
Iwakuni MCAS	0	0	12	**12**
Miho JASDF AB	3	2	0	**5**
Iruma JASDF AB	3	2	0	**5**
Gifu JASDF AB	2	2	0	**4**
Saipan International	2	2	0	**4**
Kanoya JMSDF AB	0	0	12	**12**
Futenma MCAS	4	2	0	**6**
Hamamatsu JASDF AB	4	1	0	**5**
Nyuutabaru JASDF AB	3	2	0	**5**
Tsuiki JASDF AB	3	2	0	**5**
Hyakuri JASDF AB	2	2	0	**4**
Total	**269**	**61**	**120**	**450**

Scenario 4 is a model of the Air Force's Agile Combat Employment (ACE) doctrine. It takes the same number of aircraft as the previous scenarios (450) and deploys them to a representative sample of air bases from a broader collection of bases. Our model of ACE builds its analysis on five key variables: (1) The deployment set: the number of bases in the theater that are prepared to operate aircraft (e.g., where adequate ammunition, fuel, spare parts, and other supplies are prepositioned to support sustained operations); (2) The active bases: the number of bases from which U.S. forces will operate at any given time. The number of active bases will be smaller than the deployment set, which is why People's

Liberation Army (PLA) targeters will have difficulty determining which bases (among the deployment set) are in use;[12] (3) The movement rate: the number of days that U.S. units operate from a given base before moving to another base within the deployment set; (4) The movement delay: the amount of time that operations are delayed each time a unit moves from one base to another; and (5) ISR degradation effectiveness: captures the effect of a range of activities the United States may take to reduce the effectiveness of PLA intelligence, surveillance, and reconnaissance (ISR) in the theater.[13] If the United States chooses not to significantly degrade PLA ISR (or if the U.S. is ineffective in its efforts to do so) then the value of the degradation variable is "none," in which case PLA targeters can determine which bases the USAF is using at any given time (i.e., which facilities are the active bases) and direct their missile fire there. At the other end of the continuum, if ISR degradation is full, then PLA targeters cannot identify the active bases and must divide their missile fire over the entire deployment set. If ISR degradation is moderate, PLA targeters can glean some information to help them identify the active bases, and their targeting efficiency is at the midpoint between "none" and "full."[14]

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[12] Note that the ACE model assumes that PLA targeters can determine which bases are in the "deployment set" because they can observe the peacetime and crisis preparations for operations there, but they do not necessarily know which bases are being used at any given time (i.e., they don't know which are the active bases).

[13] The United States could employ a wide range of approaches to degrade PLA ISR during a war, depending on the willingness of U.S. and political leaders to authorize potentially escalatory activities. For example, focusing on the anti-satellite component of these efforts, U.S. approaches could include jamming the sensors on satellites, damaging the sensors, destroying or de-orbiting satellites, and jamming communication and control of satellites. These activities could be attempted using a combination of lasers, various EW approaches, cyber attacks, and more. A full-scale counter-satellite effort would likely also include attacks on PLA ISR data integration sites and command and control facilities on the Chinese mainland. Note that counter-satellite efforts would be only one part of a wider counter-ISR effort, if the United States wished to maximize PLA targeting difficulties. Other targets would include undersea sensors, UAVs and their control systems, land-based over-the-horizon radars, and more.

[14] Note that the model does not presume that the United States will conduct major operations against PLA ISR. Instead, it explores the consequences for U.S. effectiveness of adopting either a restrained, moderate, or unrestrained level of effort against China's regional ISR and command and control.

To use the ACE model the user selects the number of airfields in the deployment set, the number of active bases, the movement rate, the movement delay, and the extent of PLA ISR degradation (none, moderate, or full). As a baseline, we assume there are 40 bases in the deployment set, 20 active bases, that aircraft move every five days, and that moving involves 1 day of delayed operations. Once these inputs are selected, the model then automatically deploys aircraft to bases according to the same rules as in the U.S. 6, Dispersed to 15, and Dispersed to 24 Bases scenarios (above): starting with the DCA mission, then filling HAS, and then deploying proportional to parking. Table C5 presents the list of bases and the number of aircraft deployed to each in this scenario.

Table C5: Agile Combat Employment (ACE), Bases and Aircraft Deployment				
Base	**5th Gen. Aircraft**	**4th Gen. Aircraft**	**DCA Aircraft (4th Gen.)**	**Total**
Misawa AB	40	0	12	**52**
Chitose JASDF AB	43	4	12	**59**
Andersen AB	66	13	12	**91**
Clark AB	37	1	24	**63**
Guam International	18	7	0	**26**
Komaki JASDF AB	18	1	12	**31**
Atsugi JMSDF AB	12	6	0	**18**
Kanoya JMSDF AB	9	0	12	**21**
Miho JASDF AB	7	0	12	**19**
Hamamatsu JASDF AB	6	4	0	**10**
Hyakuri JASDF AB	5	4	0	**9**
Saipan International	0	4	0	**4**
Nyuutabaru JASDF AB	2	2	0	**4**
Iwo Jima JASDF AB	0	0	12	**12**
Cesar Basa PAF AB	2	2	0	**4**
Tsuiki JASDF AB	3	1	0	**4**
Edwin Andrews PAF AB	0	0	12	**12**
Rota International	0	4	0	**4**
Tinian International (West AF)	0	4	0	**4**
Naval Station Ernesto Ogbinar	0	4	0	**4**
Total	**259**	**61**	**120**	**450**

Finally, Scenario 5 modifies the Dispersed to 24 Bases scenario (i.e., Scenario 3) by envisioning a major HAS-building campaign, adding 300 additional HAS across the 24 bases. The 300 HAS were distributed across the 24 bases using the following priorities: (1) distribute them broadly across the 24 bases, to mitigate risk of a PLA "pin down" attacks at specific bases; (2) prioritize U.S. bases, U.S. territories, and U.S. allies who have lasting and close relations with the U.S. and whose airfields have few HAS (i.e., Japan); and (3) distribute them in approximate groups of four (to match a U.S. Air Force "flight" size). Table C6 presents the list of bases, the number of aircraft deployed to each base, and the additional HAS at each base in this scenario.

Table C6: Dispersed to 24 + 300 HAS, Bases, Aircraft, & HAS

Base	5th Gen. Aircraft	4th Gen. Aircraft	DCA Aircraft (4th Gen.)	Total Aircraft	Preexisting HAS	Additional HAS	Total HAS
Andersen AB	38	2	12	**52**	0	42	**42**
Kadena AB	26	6	24	**56**	15	27	**42**
Chitose JASDF AB	18	10	12	**40**	14	22	**36**
Yokota AB	11	2	12	**25**	0	18	**18**
Misawa AB	21	0	12	**33**	31	0	**31**
Komatsu JASDF AB	12	1	0	**13**	10	2	**12**
Guam International	18	2	0	**20**	0	18	**18**
Clark AB	0	5	24	**29**	0	24	**24**
Villamor PAF AB	7	4	0	**11**	0	6	**6**
Cesar Basa PAF AB	6	1	0	**7**	2	4	**6**
Komaki JASDF AB	12	2	0	**14**	0	12	**12**
Naha JASDF AB	12	2	0	**14**	2	10	**12**
Atsugi JMSDF AB	6	2	0	**8**	0	6	**6**
Iwakuni MCAS	8	1	12	**21**	0	18	**18**
Miho JASDF AB	6	1	0	**7**	0	6	**6**
Iruma JASDF AB	6	1	0	**7**	0	6	**6**
Gifu JASDF AB	6	1	0	**7**	0	6	**6**
Saipan International	12	1	0	**13**	0	12	**12**
Kanoya JMSDF AB	2	12	12	**26**	0	24	**24**
Futenma MCAS	18	1	0	**19**	0	18	**18**
Hamamatsu JASDF AB	6	1	0	**7**	0	6	**6**
Nyuutabaru JASDF AB	6	1	0	**7**	2	4	**6**
Tsuiki JASDF AB	6	1	0	**7**	3	3	**6**
Hyakuri JASDF AB	6	1	0	**7**	0	6	**6**
Total	**269**	**61**	**120**	**450**	**79**	**300**	**379**

D) Forces

On the U.S. side, our analysis includes aircraft operated by the U.S. Air Force, the U.S. Air Force Reserves, and the U.S. Air National Guard. Table D1 (below) presents U.S. fighter and tanker aircraft that are included in the analysis, along with some of their relevant specifications. We make the following baseline assumptions with respect to the availability of U.S. aircraft in our scenarios:

- 70% of U.S. aircraft are mechanically ready for combat missions;[15]
- 1/3 of 4th generation fighter aircraft that are mechanically ready are available for the mission;
- 2/3 of 5th generation fighter aircraft that are mechanically ready are available for the mission;
- 1/2 of tanker aircraft that are mechanically ready are in-theater and available for the mission.[16]

[15] This is a reasonable, even somewhat conservative, assumption as it is effectively the U.S. Air Force's current, relative-peacetime mission-capable rate (John A. Tirpak, "Air Force Mission Capability Rates Reach Lowest Levels in Years," *Air & Space Forces Magazine*, February 18, 2025, https://www.airandspaceforces.com/air-force-mission-capable-rates-fiscal-2024/). It is also worth noting that during the 1991 Gulf War, mission capable rates for key fighter and tanker aircraft remained considerably higher: F-15 (88.5%+), F-16 (89.8%+), KC-10 (86.7%+), KC-135R (84.7%+). See: *Gulf War Air Power Survey*, Vol. V: *A Statistical Compendium and Chronology* (U.S. Government Printing Office, Washington, DC: 1993), pp. 555-597 (Table 192), available at: https://media.defense.gov/2010/Sep/27/2001329816/-1/-1/0/AFD-100927-065.pdf. Previous analyses have assumed higher rates of 80% for fighters and 75% for tankers. See: David A. Shlapak et al., *A Global Access Strategy for the U.S. Air Force* (Santa Monica: RAND, 2002), pp. 58, 59.

[16] This also seems reasonable, given that, at the peak of the 1991 Gulf War, the U.S. had devoted 81 percent of its KC-10s and 44 percent of its KC-135s to the war. See: *Gulf War Air Power Survey,* Vol. III: *Logistics and Support* (U.S. Government Printing Office, Washington, DC, 1993), p. 180.

Table D1: U.S. Air Force Aircraft Inventory & Relevant Specifications

Fighter Aircraft

Model	Generation	Count[a]	Max. range (km)	Average cruising speed (km/h)	Fuel capacity (kg)	Armament
F-15C Eagle	4	105	2,458[c]	915[g]	6,103[h]	6 AIM-120, 2 AIM-9[l]
F-16C Fighting Falcon		682	2,186[d]		3,228[i]	4 AIM-120, 2 AIM-9[m]
F-22A Raptor	5	153[b]	2,058[e]		8,165[j]	6 AIM-120, 2 AIM-9[n]
F-35A Lightning		424	2,222[f]		8,278[k]	4 AIM-120, 2 AIM-9[o]

Tanker Aircraft

Model	Count[a]	Fuel delivery capacity (kg)[p]	Average cruising speed (km/h)
KC-46A Pegasus	89	94,347	888[q]
KC-135R/T Stratotanker	371	90,718	

[a] *The Military Balance, 2025* (London: The International Institute of Strategic Studies, 2025), pp. 45-46.
[b] We subtract 32 Block 20 F-22A's from the *Military Balance*'s total of 185 because the U.S. Air Force does not consider them to be combat capable. See: Audrey Decker, "F-22s Marked for Retirement Will Never Be Combat Worthy, General Says," *Defense One* (April 6, 2023), https://www.defenseone.com/policy/2023/04/f-22s-marked-retirement-will-never-be-combat-worthy-general-says/384916/.
[c] Janes estimates that the F-15C has a ferry range of 4,630 km with three external fuel tanks, with each external tank having 1,798 kg capacity. We reduce the maximum range by the share of the reduction in external fuel capacity by flying without external fuel tanks (4,630 km * 6,103 kg/(6,103 kg + (1798 kg * 3)) = 2,458 km). *Janes All the World's Aircraft: In Service, 2021-2022* (Coulsdon: IHS Global, 2021), p. 197.
[d] Janes estimates that the F-16C has a ferry range of 3,981 km with external fuel tanks. We reduce this maximum range by the share of the reduction in external fuel capacity by flying without external fuel tanks (3,981 km * 3,228 kg/5,879 kg = 2,186 km). *Janes All the World's Aircraft: Development & Production, 2022-2023* (Coulsdon: IHS Global, 2022), p. 1008.
[e] The U.S. Air Force lists the F-22's ferry range "with two external wing fuel tanks" at 2,977 km, and each external fuel tank has an 1,823 kg capacity. We reduce the ferry range by the share of the reduction in external fuel capacity by flying without external fuel tanks (2,977 km * 8,165 kg/(8,165 kg + (1,823 kg * 2)) = 2,058 km. "F-22 Raptor," U.S. Air Force (August 2022), https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104506/f-22-raptor/; *Janes All the World's Aircraft: In Service, 2021-2022*, p. 421.
[f] "F-35A Lightning II," U.S. Air Force (April 2014), https://www.af.mil/About-Us/Fact-Sheets/Display/Article/478441/f-35a-lightning-ii/.
[g] This is the estimated cruising speed for the F-15, which we assume is similar for all other aircraft. "F-15 Eagle," Global Security (2023), https://www.globalsecurity.org/military/systems/aircraft/f-15-specs.htm.
[h] *Janes All the World's Aircraft: In Service, 2021-2022*, p. 197.
[i] *Janes All the World's Aircraft: Development & Production, 2022-2023* (Coulsdon: IHS Global, 2022), p. 1008.
[j] "F-22 Raptor," U.S. Air Force (2022).
[k] *Janes All the World's Aircraft: Development & Production, 2022-2023*, p. 1014.
[l] "F-15 Eagle," *Air & Space Forces Magazine* (2023), https://www.airandspaceforces.com/weapons-platforms/f-15/.
[m] *Janes All the World's Aircraft: Development & Production, 2022-2023*, p. 1004.
[n] *Janes All the World's Aircraft: In Service, 2021-2022*, p. 421.
[o] "F-35 Lightning II American Multirole Combat Aircraft," U.S. Army, OE Data Integration Network (ODIN), Worldwide Equipment Guide (WEG) v3.2.2 (2023), https://odin.tradoc.army.mil/WEG/Asset/F-35_Lighting_II_American_Multirole_Combat_Aircraft.
[p] *Air Force Pamphlet 10-1403: Air Mobility Planning Factors* (Department of the Air Force, 24 October 2018), p. 18 (Table 10).
[q] This is the KC-135's cruising speed, which we assume is similar for the other tanker aircraft. "KC-135 Stratotanker," *Air & Space Forces Magazine* (2023), https://www.airandspaceforces.com/weapons-platforms/kc-135/.

China's main forces in the analysis are its People's Liberation Army Rocket Forces (PLARF). Table D2 presents the ballistic and cruise missiles that are included in the analysis, along with some of their relevant specifications. We make the following baseline assumptions about China's missile forces:

- 2/3 of the PLARF's missile force is available for the mission (with the remaining 1/3 being held in reserve);
- 90% of the missiles successfully launch when intended.[17]

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[17] This assumption is in line with previous analyses. Heginbotham et al. assume 75 percent missile reliability (Eric Heginbotham, et al., *The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996-2017* (Santa Monica, RAND Corporation, 2015), p. 60), whereas Shlapak et al. assume 85 percent missile reliability (David A. Shlapak, et al., *A Question of Balance: Political Context and Military Aspects of the China-Taiwan Dispute* (Santa Monica: RAND Corporation, 2009), p. 39). Stillion and Orletsky's assumptions vary by missile, and range from 50 percent to 95 percent (John Stillion and David T. Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks: Technology, Scenarios, and U.S. Air Force Response* (Santa Monica: RAND Corporation, 1999), p. 79).

Table D2: PLARF Missiles in Analysis & Relevant Specifications					
Category	**Model**	**Count[b]**	**Max. range (km)[d]**	**Warhead weight (kg)**	**Accuracy (m CEP)[i]**
Short-Range Ballistic Missiles (SRBM)	DF-11A	432	600	600[f]	20
	DF-15B	324	850		
	DF-16A	144	1,000		
Medium-Range Ballistic Missiles (MRBM)	DF-17	612	1,600		
	DF-21C[a]	306	1,500		
Intermediate-Range Ballistic Missile (IRBM)	DF-26	500	4,000	1,800[g]	150[j]
Ground-Launched Cruise Missile (GLCM)	CJ-10	229	2,200	400[h]	10
	CJ-100	171	2,000		
Air-Launched Cruise Missile (ALCM)	CJ-20	200[c]	2,500[e]		

[a] Many have begun to assume that the DF-21C is being phased out in favor of the DF-26, though others suggest it is still operational. Because of the uncertainty surrounding its operational status, we include it in our analysis.

[b] Unless otherwise noted, our count estimates combine U.S. Department of Defense (DOD) estimates of the number of missiles by category with *The Military Balance*'s estimates of the number of launchers by missile model. We multiply the number of missiles estimated (by the DOD) in each category by the share of launchers estimated (by *The Military Balance*) for each missile type within that category. For example, the DOD estimates that the PLA has 900 SRBMs and *The Military Balance* estimates that the PLA has 108 DF-11A launchers, 81 DF-15B launchers, and 36 DF-16 launchers. We combine these and estimate that the PLA has 432 DF-11s (900 * (108/(108+81+36))), 324 DF-15Bs (900 * (81/(108+81+36))), and 144 DF-16As (900 * (36/(108+81+36))). See: *The Military Balance 2025*, p. 240; *Military and Security Developments Involving the People's Republic of China, 2024* (Washington: Department of Defense, 2024), p. 66. DF-21C launcher estimate from: *The Military Balance 2022* (London: The International Institute of Strategic Studies, 2022), p. 255.

[c] China's ALCM inventory is not known in the open-source literature, so we assume they employ the average of the two types of GLCMs.

[d] Estimates of the range of China's missiles vary quite widely, and we've simplified them here for analytical purposes. Unless otherwise noted, sources for the range estimates are: *Military and Security Developments Involving the PRC*, pp. 63-66; *China Military Power, 2019* (Washington: Defense Intelligence Agency, 2018), p. 93; Lee Willett, *Janes Weapons: Strategic, 2021-2022* (Coulsdon: IHS Janes, 2021), pp. 9-20, 21-22, 137-139.

[e] The Army's Worldwide Equipment Guide (WEG) assumes the CJ-20 has a range of 2,000 km. For the purpose of our analysis, we assume Chinese aircraft can safely travel no more than 500 km from their coast in order to launch air-launched cruise missiles, giving the CJ-20 a maximum range of 2,500 km from the Chinese coast. See: "Changjian-20 (CJ-20) Chinese Long-Range Cruise Missile," U.S. Army, ODIN, WEG (2023), https://odin.tradoc.army.mil/WEG/Asset/Changjian-20_(CJ-20)_Chinese_Long-Range_Cruise_Missile.

[f] PLARF missile warheads vary in size. We simplify here for analytical purposes. See: Willett, *Janes Weapons: Strategic, 2021-2022*, pp. 10-11, 13-15, 16-20; "DF-16 (Dongfeng 16) Chinese Short-Range Ballistic Missile," U.S. Army, ODIN, WEG (2023), https://odin.tradoc.army.mil/WEG/Asset/DF-16_(Dongfeng_16)_Chinese_Short-Range_Ballistic_Missile.

[g] "DF-26 (Dongfeng 26) Chinese Intermediate-Range Ballistic Missile," U.S. Army, ODIN, WEG (2025), https://odin.tradoc.army.mil/WEG/Asset/DF-26_(Dongfeng_26)_Chinese_Intermediate-Range_Ballistic_Missile.

[h] Heginbotham, et al., *The U.S.-China Military Scorecard*, p. 48.

[i] Estimates of the accuracy of PLARF missiles vary widely. We simplify here for analytical purposes. Sources for our estimates include: Heginbotham, et al., *The U.S.-China Military Scorecard*, p. 48; Willett, *Janes Weapons: Strategic, 2021-2022*, pp. 9-20, 21-22, 137-139.

[j] While the U.S. Department of Defense has made reference to the DF-26's ability to conduct "precision land-attack and anti-ship strikes" (*Military and Security Developments Involving the PRC*, p. 65), specific, publicly available estimates still see the DF-26's accuracy at 150 m CEP. See: Willett, *Janes Weapons: Strategic, 2021-2022*, p. 22; "DF-26 Chinese IRBM," U.S. Army, ODIN, WEG.

E) The Offensive Counterair Mission & Sortie Generation Model

The model depicts an effort by the United States to use land-based airpower to prevent China from achieving air superiority over Taiwan in the context of a cross-strait war. In our baseline scenario, the USAF is imagined to be conducting "offensive counterair" operations against the People's Liberation Army Air Force (PLAAF). More specifically, it is envisioned as engaging in fighter sweep operations into PLAAF patrols east of Taiwan in order to "seek out and destroy enemy aircraft or targets of opportunity" in the area.[18] In practical terms, this would involve U.S. fighter aircraft based in the region taking off from their bases, flying to an area a few hundred kilometers off of Taiwan's east coast, refueling in the air via U.S. tanker aircraft, sweeping through and firing air-to-air missiles at People's Liberation Army (PLA) aircraft on patrol near Taiwan, and then flying back to base. The aircraft would then undergo routine maintenance and refueling while the pilot rested, and then the aircraft would be ready for another mission. Each one of these cycles is known as a "sortie."[19] At the core of our analysis is a sortie generation model.

Sortie Generation Model

The foundation of the sortie generation model is a simple formula that estimates U.S. Air Force sortie rates as a function of the flight time of each aircraft's mission:[20]

$$sortie\ rate = \frac{24\ hours}{flight\ time + ground\ time}$$

[18] *Joint Publication 3-01: Countering Air and Missile Threats* (Washington: Joint Chiefs of Staff, April 2017), IV-17 to IV-18; *Air Force Doctrine Publication 3-01: Counterair Operations* (Maxwell AFB: United States Air Force, June 2023), pp. 4-5.
[19] *Joint Publication 3-30: Joint Air Operations* (Washington: Joint Chiefs of Staff, September 2021), GL-7.
[20] What follows is based on: Eric Stephen Gons, *Access Challenges and Implications for Airpower in the Pacific*, Ph.D. Dissertation (Santa Monica: Rand Corporation, May 2010), pp. 201-208 (Appendix A).

The flight time of a sortie is the distance flown by the aircraft divided by the cruising speed of the aircraft plus the time spent on station and refueling. For the fighter sweep mission, we assume that aircraft spend an average of 30 minutes on station. We also assume that each aerial refueling takes 15 minutes (0.25 hours).[21] The ground time of a sortie is the time engaged in various tasks such as maintenance, refueling, rearming, and debriefing.[22] Following RAND analyses, we assume that there is a fixed 3 hours of "turnaround time," a fixed 3.4 hours of routine maintenance, and a variable amount of maintenance depending on the aircraft's previous flight time. The variable amount of maintenance is calculated as the previous flight time * 0.68. Thus, the entire daily sortie rate formula is:

$$sortie\ rate = \frac{24\ hours}{\left(2 * \left(\frac{distance}{crusing\ speed}\right)\right) + (\#\ refuels * 0.25) + time\ on\ station + 3 + 3.4 + \left(2 * \left(\frac{distance}{crusing\ speed}\right) * 0.68\right)}$$

For safety reasons, the U.S. Air Force mandates aircrew rest and limits the amount of flying time pilots can log (there are also important physical limitations to long-endurance missions).[23] To account for this, we limit the number of sorties that can be flown in a given 24-hour period to 1 sortie if the total flight time for the mission is greater than 8 hours.

[21] This is a conservative assumption, given that the tanker aircraft in the U.S. fleet can transfer fuel at a rate of over 3,000 kg/minute, transferring the amount needed to fill an F-35 (8,278 kg), for instance, in under three minutes. The KC-135R/T's fuel transfer rate is 3,242 kg/minute ("KC-135 Stratotanker," *Air & Space Forces Magazine* (2023), https://www.airandspaceforces.com/weapons-platforms/kc-135/) and the KC-46A's fuel transfer rate is 3,538 kg/minute ("KC-46 Pegasus," *Air & Space Forces Magazine* (2023), https://www.airandspaceforces.com/weapons-platforms/kc-46/). See also: Gons, *Access Challenges and Implications for Airpower in the Pacific*, pp. 202-203, 207.

[22] For details, see: Stillion and Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks*, p. 83; Gons, *Access Challenges and Implications for Airpower in the Pacific*, p. 204.

[23] Fighter pilots are limited to 12 hour "flight duty period" in a single day, 56 hours per seven consecutive days (eight hours/day), and 125 hours per 30 consecutive days (4.2 hours/day). See: *Air Force Manual 11-202*, Vol. 3: *Flight Operations* (Maxwell AFB: United States Air Force, January 2022), pp. 31-32. For a good description of the physical limitations of long missions, see: Christopher Bowie, *The Anti-Access Threat and Theater Air Bases* (Washington: CSBA, 2002), pp. 11-13.

This all provides the maximum sortie rate for aircraft with a given mission deployed to given bases. However, the fighter sweep operation involves the U.S. Air Force sending large numbers of aircraft to contest the PLAAF's defensive patrols in a coordinated fashion a number of times per day. As a baseline, we assume that the U.S. sends two fighter sweep sorties per day to challenge the PLAAF combat air patrol (CAP) over Taiwan. As a baseline, we limit the size of each U.S. fighter sweep to a maximum of 72 aircraft, with 10 percent being dedicated to electronic warfare and/or suppression of enemy air defense (SEAD).[24] The model also incorporates the idea that coordinating such large sweeps involves logistical challenges, since aircraft may be highly dispersed at different bases throughout the theater of operations and at different distances to refueling locations and to Taiwan. What this means is that aircraft will not necessarily takeoff for a sweep mission the moment they are ready and will not operate at the maximum tempo allowed by their sortie rates. They will often have to wait for a critical mass of other aircraft to be ready for the mission in order to take off. Thus, the model assumes that sweeps occur at an approximately regular interval throughout the day, though not necessarily at a predicable time.[25] It then compares the total sortie time for aircraft at given bases (that is, flight time + ground time) to the interval of sweep missions over 24 hours in order calculate how many hours will pass until the next sweep occurs. This delay is then added to the total sortie time and therefore reduces the sortie rate for aircraft operating from most bases.[26] Figure E1

[24] Thus, even if the U.S. has 200 offensive counter air sorties available on a given day, if it plans to conduct just two sweeps, then the most it will actually send is 144 (that is, 72 * 2) and the most that would be dedicated to the fighter sweep mission is 130 (144 * 0.9)
[25] Thus, if the user decides on two sweeps per day, they will occur roughly twelve hours apart. If the user decides on three sweeps per day, they will occur roughly eight hours apart.
[26] Note that this also increases the ground time for aircraft flying fighter sweep missions, which has an impact on how the effects of missile attacks are calculated. See Appendix G.

(below) shows a simple diagram of how the model conceives of the operation under the U.S. 6 Bases scenario.

Figure E1: Diagram of U.S. 6 Bases

Note: Kadena Air Base is also included in the U.S. 6 Bases scenario, but is obscured here by its close proximity to Futenma MCAS. The map was generated by the authors using Google My Maps.

It is also important to note that not all aircraft on each base are assigned to the fighter sweep mission over Taiwan. A portion of the aircraft in the analysis are assigned to conduct a defensive counterair (DCA) mission over their bases of operation. We assume that

geographically proximate bases share defensive counter air assets based on what we refer to as "air defense zones," which are all listed in Table C1, above. As a baseline, we assume that each air defense zone requires 12 or 24 dedicated aircraft, depending on their proximity to China and the air and missile threats the bases face in the zone face.[27] We also assume as a baseline that 50 5th generation aircraft are set aside for other vital missions in the region, such as escorting bombers, tankers, and maritime patrol aircraft; defensive counter air missions in other parts of the theater; and possible strikes against targets on the mainland. Once selected into this category, these other aircraft will not be available for fighter sweep missions over Taiwan for the remainder of the run of the model. The loss rate for these "other" aircraft's missions is also a model input, which we assume to be 0.5% of these aircraft per day.

In sum, using the formula presented above, and given the deployment of any number of aircraft into bases across East Asia, we can calculate the duration of their sorties, their daily sortie rates, and the number of aircraft that fly fighter sweep missions over Taiwan on a daily basis. The key output of the sortie model is how many U.S. fighter sweep sorties over Taiwan can be generated on a daily basis.

Modeling Sorties Under Agile Combat Employment (ACE)

Our analysis of U.S. sorties under the Agile Combat Employment (ACE) scenarios involves some additional considerations. Because ACE envisions U.S. air forces trying to use mobility to enhance their survivability, we had to make assumptions about how often U.S. air forces will move and what these movements cost it in terms of logistics and, ultimately, sorties to

[27] We assume the following air defense zones require 24 aircraft: Okinawa, Japan (#1); South Korea (#8); Luzon, Philippines (#11); northern Thailand (#17); central Thailand (#18). See Table C1, above.

Taiwan. After selecting the number of bases in the deployment set and active bases (see Appendix C, above), the model user then selects how often U.S. aircraft will relocate from one base to another in the deployment set. As a baseline, we assume this is every five days. The model doesn't necessarily imply that all U.S. aircraft in the theater move simultaneously every five days. The way we've modeled it is more consistent with subsets of bases moving each day and that every 5 days all bases will have relocated once. We also had to make assumptions about how long it takes to pack up at one base, relocate, and then set up at another base and be ready for action. After selecting how often U.S. aircraft will relocate in the deployment set, the model user then selects how much mission time is lost with each move. As a baseline, we assume that each move costs one day. In practical terms this means that a set of aircraft that relocate from one base to another will lose 24 hours of fighter sweep sorties against PLAAF forces near Taiwan.

It is important to note that the model doesn't actually have aircraft move from one base to another. What it does instead, as noted above, is initially place the aircraft in a representative sample of active bases from the broader deployment set. Then it applies a sortie rate limiter or logistics "penalty" based on how often the user has opted to move and how long each move takes. As noted above, we assume as a baseline that aircraft relocate their bases every five days and that each move takes one day. This means that under ACE the U.S. is losing 20% of its sorties, since it is losing one full day by relocating every five days.[28] This penalty is applied to the sortie rate for each base which then reduces the overall number of sorties the model simulates the U.S. as flying over Taiwan. Modeling ACE also has implications for PLA missile strikes, which we discuss below (see Appendix G).

[28] That is, 1/5 = 20%.

F) Aerial Refueling & The Aerial Refueling Model

As noted above, all aircraft flying missions over Taiwan will refuel before arriving on station. In our analysis, all aircraft refuel at a location approximately 590 kilometers east of the geographic center of Taiwan.[29] We refer to this refueling point as "Refueling Orbit 1" or "O1." This distance provides a safe buffer from People's Liberation Army Air Force (PLAAF) fighter aircraft conducting defensive counterair missions, giving vulnerable U.S. tanker aircraft ample time to fly away if need be (something referred to as "slide and scram" in Air Force parlance).

However, some aircraft may operate from bases whose distance from O1 is beyond their unrefueled range. For instance, Andersen Air Force Base on the U.S. island territory Guam is about 2,170 kilometers from O1, which is beyond the F-35A's safe range of 2,000 kilometers (see Table D1, above),[30] as well as other fighter aircraft operating without external fuel tanks. Similarly, Japan's Chitose Air Base, on the northern island of Hokkaido, is 2,707 kilometers from O1, also beyond the unrefueled range of U.S. fighters. As part of our analysis, we therefore have an aerial refueling point that services these more distant bases. We refer to this second refueling point as "Refueling Orbit 2" or "O2," and it sits roughly in between our longer-range air bases and O1.

Deciding where to locate the secondary refueling point (O2) is a complex matter. It depends, among other things, on which bases are in operation, the location of the primary refueling point (O1), the unrefueled ranges of the aircraft conducting fighter sweep sorties,

[29] The coordinates of the refueling point in our analysis are: 21.9898833461, 126.429992364. The coordinates for the geographic center of Taiwan are: 23.9738682657, 120.98202697. Note, of course, that these are model inputs—users can adjust these locations as they see fit.

[30] The safe range here refers to the aircraft's maximum range minus a ten percent fuel reserve, so: 2,222 km * (1-0.1) = ~2,000 km. 10 percent is a standard fuel reserve for the U.S. Air Force. See: Shlapak et al., *A Global Access Strategy*, p. 57.

and the base(s) from which tanker aircraft are flying their own refueling sorties. With certain combinations of bases, such as a deployment that included bases in Thailand and those in northern Japan, one would actually need at least two O2s, since the distance between these geographic areas means that there are no points on the map that could reasonably refuel aircraft from both areas.[31]

Our model locates O2 dynamically, automatically placing it in a different location dependent upon which bases the user has selected as being part of the operation. We made two important assumptions regarding O2 and its location. First, we assume that there is just a single O2. Having multiple O2s to serve different collections of bases would help increase the route efficiency for fighters and thereby help maximize sortie rates, but at the cost of a highly complex set of refueling operations that would involve significant logistical challenges. Second, we assume that O2 is located, not to maximize sortie efficiency, but to allow the servicing of as many bases as possible. The model identifies the two most geographically extreme bases, automatically finds the area in space that would allow both to be refueled, and places O2 in that area at the closest possible point to O1. O2 is located to accommodate aircraft that may be flying without external fuel tanks, meaning that it must be 1,926 kilometers or closer to all bases in the simulated scenario (this is the average of the U.S.'s 5th generation aircrafts' ranges minus a 10 percent reserve[32]).

We therefore have the primary refueling point (O1) in a fixed location and a secondary refueling point (O2) located dynamically depending on which bases are part of the

[31] To illustrate, a straight line between Japan's Chitose Air Base and Thailand's Korat Royal Thai Air Force Base is nearly 5,000 kilometers long and passes almost 600 kilometers west of Taiwan, directly over China's territory.
[32] That is, ((2,222+2,058)/2) * (1-0.1) = 1,926.

operation. All aircraft flying sweep missions over Taiwan must refuel at O1 whereas only those operating from distant bases must additionally refuel at O2.

Aerial Refueling Model

Using the information on the number of aircraft in the operation, the bases from which they are operating, and the locations of O1 and O2, the model then calculates both the demand for aerial fuel generated by the operation and the U.S.'s ability to supply that fuel using tanker aircraft on a daily basis. (The model also uses these calculations—of the specific routes flown by different aircraft from different bases—to estimate the flight time for the aircraft at each base, which feeds into the sortie generation model presented in Appendix E, above.)

To start with fuel demand, the model assumes that all aircraft takeoff from their bases with full fuel tanks and proceed either to O2 (if more distant) or directly to O1 (if closer in) for aerial refueling. It then assumes that they complete their fighter sweep mission and return the way they came, refueling (first) at O1 (and for some again at O2) before returning to their home bases. It then uses information on the aircrafts' internal fuel capacities, estimates of their average fuel "burn rates," the number of aircraft involved, and their sortie rates, to calculate how much aerial fuel is demanded at O1 and O2 in a single day.[33] In our analysis, we simplify for analytical purposes by taking the weighted (by

[33] To illustrate, an F-35A flying from Andersen Air Force Base would first refuel at an O2 near the midpoint of Andersen and O1 (around this point, here: 18.0013767046, 135.904604676), then refuel at O1, would then conduct its fighter sweep mission for approximately 30 minutes, would then refuel again at O1, proceed to refuel at O2, and then return to Andersen. The F-35A has an internal fuel capacity of 8,278 kg. Using its estimated maximum range of 2,222 km, we can estimate its average fuel burn rate: 8,278 kg / 2,222 km = 3.73 kg/km. The distance from Andersen to O2 in this case is approximately 1,085 km, as is the distance from O2 to O1. Therefore, the F-35 would burn about 4,047 kg of fuel (3.73 kg/km * 1,085 km) on its trip from Andersen to O2, and would refill this amount of fuel (4,047 kg) from a tanker. It would then proceed to O1 and would top up approximately the same amount (4,047 kg), since it is the same distance. From there it would fly to and conduct its fighter sweep mission over Taiwan before returning back to O1 to refill with

number of aircraft) average of the fuel capacities and estimated burn rates of the 4th generation aircraft[34] and the 5th generation aircraft[35] separately and use those for our calculations. Thus, the model calculates daily 4th generation aircraft aerial fuel demand at O1 and O2 as well as daily 5th generation aircraft aerial fuel demand at O1 and O2. It is important to note that ground refueling is not accounted for in the model and is assumed for analytical purposes to be effectively unlimited.

The analysis also models the U.S.'s ability to supply its mission with aerial fuel using tanker aircraft. The model allows the user to select up to twenty-five bases from the regional bases from which tanker aircraft will operate.[36] In our analysis, we base all of our

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6,102 kg (2 * the O1 to fighter sweep station distance of 590 km = 1,180 km + 458 km on station flight distance (30 min./60 min. * 915 km/h cruising speed) = 1,638 km / 2,222 km max. F-35A range = 73.7% of fuel consumed * 8,278 kg F-35A internal fuel capacity = 6,102 kg). With its tank full, it would then proceed back to O2, filling up its tank with 4,047 kg of fuel, before returning to Andersen. Therefore, a single sortie by an F-35 from Andersen to Taiwan would demand a total of about 18,243 kg of aerial fuel—8,094 kg of it at O2 (4,047 + 4,047) and 10,149 kg of it at O1 (4,047 + 6,102). This figure can be then multiplied by the sortie rate of F-35s flying out of Andersen (in this case, 1.0) and the number of aircraft flying the mission that day to get an overall estimate of daily fuel demand for the mission.

[34] For the 4th generation aircraft, the F-15C's fuel capacity is 6,103 kg and we estimate its maximum range to be about 2,458 km (see Table D1), giving it an estimated fuel burn rate of 2.48 kg/km (6,103 kg / 2,458 km). The F-16C's fuel capacity is 3,228 kg and we estimate its maximum range to be 2,186 km, giving it an estimated fuel burn rate of about 1.48 kg/km (3,228 kg / 2,186 km). In our analysis, we use the number of these aircraft in the U.S. arsenal in 2025—105 F-15Cs and 682 F-16C—to weight the average. This gives 4th generation aircraft in our analysis an average fuel capacity of 3,612 kg (6,103 kg * 105/(105+682) + 3,228 kg * 682/(105+682)), an average maximum range of 2,222 km (2,458 km * 105/(105+682) + 2,186 km * 682/(105+682)), and an average fuel burn rate of 1.61 kg/km (2.48 kg/km * 105/(105+682) + 1.48 kg/km * 682/(105+682)).

[35] For the 5th generation aircraft, the F-22A's fuel capacity is 8,165 kg and we estimate its maximum range to be about 2,058 km, giving it an estimated fuel burn rate of 3.97 kg/km (8,165 kg / 2,058 km). The F-35A's fuel capacity is 8,278 kg and its maximum range is 2,222 km, giving it an estimated fuel burn rate of 3.73 kg/km (8,278 kg / 2,222 km). In our analysis, we use the number of these aircraft in the U.S. arsenal in 2025—424 F-35As and 153 F-22As—to weight the average. This gives 5th generation aircraft in our analysis an average fuel capacity of 8,248 kg (8,165 kg * 153/(153+424) + 8,278 kg * 424/(153+424)), an average maximum range of 2,179 km (2,058 km * 153/(153+424) + 2,222 km * 424/(153+424)), and an average fuel burn rate of 3.79 kg/km (3.97 kg/km * 153/(153+424) + 3.73 kg/km * 424/(153+424)).

[36] Note, however, that tanker aircraft need longer runway lengths (minimum operating strip, or MOS) for takeoff and landing than fighter aircraft—2,133 meters at a minimum compared to just 1,525 meters for fighter aircraft—so this can be a limiting factor in base selection. They also require harder/higher grade pavement in their runways, though this is not an issue at any of the bases in our sample. For fighter aircraft MOS, see: *Air Force Pamphlet 10-219*, Vol. 4, pp. 70-71. For tanker aircraft MOS, see: *Air Force Manual 11-2KC-135*, Vol. 3, *KC-135 Operations Procedures* (Maxwell AFB: United States Air Force, September 2019), p. 55; *Air*

tanker aircraft at Royal Australian Air Force (RAAF) Darwin and RAAF Tindal, which are currently out of range of China's longest-range missiles. The model then calculates the daily sortie rates of tanker aircraft at their base(s) much like the sortie generation model described above (see Appendix E), using flight time and ground time. For flight time, we assume an average cruising speed for tanker aircraft of 888 km/h, and we assume that each tanker is on station and refueling aircraft for one hour.[37] For ground time, we assume a fixed three hours of turnaround time and a variable amount of routine maintenance time: a fixed 3.4 hours plus 0.68 times the length in hours of the previous flight. Because tanker aircraft are larger, allow for more movement within the aircraft, and are typically operated by onboard crews of 3-4, the limitations on flight times are considerably longer than for fighter aircraft, and are not a limiting factor in our analysis.[38] In sum, the following formula is used to calculate tanker aircraft sortie rates:

$$sortie\ rate = \frac{24\ hours}{\left(\frac{distance}{crusing\ speed} + 1\right) + 3 + 3.4 + \left(\frac{distance}{crusing\ speed} + 1\right) * 0.68}$$

With daily tanker aircraft sortie rates by base, we can then calculate the amount of fuel that can be delivered to O1 and O2 on a daily basis. Recall that we assume that 70% of U.S. aircraft are mechanically ready for combat missions and that 1/2 of the tanker fleet is in-theater and available for the operation being simulated (see Appendix D). The remaining 161 tanker aircraft (see Table D1) are then assigned to bases (in our case, all are stationed

Force Manual 11-2KC-10, Vol. 3, *KC-10 Operations Procedures* (Maxwell AFB: United States Air Force, January 2023), p. 20.

[37] See Table D1 for tanker cruising speed. Our one-hour on-station assumption is from *AFPAM 10-1403*, p. 18 (Table 10 note 6).

[38] The maximum flight duty period for tanker aircraft is between 16 and 24 hours, depending on aircraft provisions. See: *AFMAN 11-202*, Vol. 3, pp. 31-32.

at Darwin and Tindal[39]) and assigned to fly refueling missions to either O1 or O2. U.S. Air Force planning numbers are then used to calculate the amount of fuel that each tanker aircraft can deliver to their assigned location based on its distance, or "mission radius."[40] Then the number of aircraft by base, their sortie rates, and the amount of fuel they can deliver for each sortie is combined to calculate how much fuel can be delivered to O1 and O2 for each base in a single day. We assume as a baseline that there is no aerial attrition for tanker aircraft in our analysis, however the model has the option of including a daily tanker aerial attrition rate (%). Since we base all tankers at Darwin and Tindal, out of China's missile range, we don't have any ground attrition of tanker aircraft either, though the model also allows for ground attrition. If the user bases tankers within missile range, they will be attrited on the ground in the same way that fighters parked in the open are attrited by missile attacks (see Appendix G).

[39] Previous analyses have estimated that tanker aircraft require approximately 3,800 m^2 of parking space each. With Darwin having a total parking area of 717,800 m^2 and RAAF Tindal having a total parking area of 1,161,050 m^2, there would be ample space for the tankers across these two bases ((717,800 + 1,161,050) / 161 tankers = 11,670 m^2 per tanker). See: Shlapak et al., *A Global Access Strategy*, pp. 49-50.

[40] The data are from *AFPAM 10-1403*, p. 18 (Table 10). Note that the table only includes four distances and their associated tanker fuel offload capabilities: 500 nautical miles (926 km), 1,000 nm (1,852 km), 1,500 nm (2,778 km), and 2,500 nm (4,630 km). We make linear extrapolations between these datapoints to fill in missing data, and we continue the linear trend up to 9,999 km.

G) Missile Attacks on Bases

The model analyzes the impacts of People's Liberation Army Rocket Forces (PLARF) missile attacks on U.S. bases. As noted above, as a baseline we assume that up to 2/3 of the People's Liberation Army's (PLA) missile stocks are available for use and that the missiles employed are 90% reliable. We also assume that the PLA Rocket Forces operate within a 100 km radius of their brigade headquarters. What this means in practical terms is that the ranges of PLARF missiles listed in Table D2 (above) are measured, not from the Chinese coast, but from these specific bases plus 100 km. The PLA Rocket Force brigades that are included in our analysis are presented in Table G1 (below), along with some of their relevant characteristics. We assume that the PLARF's missile stocks (see Table D2, above) are evenly divided by type between their respective brigades.[41]

[41] By this we mean, for instance, that China's estimated 324 DF-15s are evenly divided (162 each) between the 613 Brigade in Shangrao and the 616 Brigade in Ganzhou.

Table G1: PLA Rocket Force Brigades & Relevant Characteristics			
Brigade	**City**	**Coordinates**	**Missiles**
611 Brigade	Chizhou	30.689928, 117.901269	DF-26
613 Brigade	Shangrao	28.474249, 117.895578	DF-15B
614 Brigade	Yong'an	26.060300, 117.315026	DF-17
616 Brigade[a]	Ganzhou	25.833469, 114.909842	DF-15A/B/C
617 Brigade	Jinhua	29.150413, 119.615473	DF-16A/B
623 Brigade	Luorong	24.385898, 109.572331	CJ-10A
624 Brigade	Danzhou (Hainan)	19.4712340528, 109.460752497	DF-21C/D[b]
625 Brigade	Jiangshui	23.735139, 102.874978	DF-26
626 Brigade	Qingyuan	23.683975, 113.177136	DF-26
627 Brigade	Puning	23.411697, 116.181700	DF-17
635 Brigade[a]	Yichun	27.888289, 114.386869	CJ-10
636 Brigade	Shaoguan	24.755160, 113.679761	DF-16A
646 Brigade	Korla	41.695033, 86.173623	DF-26 (& DF-21C[b])
653 Brigade	Jinan	36.233844, 117.715662	DF-21C/D[b]
654 Brigade	Dalian	40.8453769717, 122.768321424	DF-26
655 Brigade	Tonghua	41.669045, 125.955439	DF-17
656 Brigade	Jinan	36.246, 117.65326	CJ-100
666 Brigade	Xinyang	32.167003, 114.125679	DF-26

[a] At the time of writing, some analysts believe these brigades may be in the process of transitioning to the DF-17. For our analysis, we assume the transition has not yet fully taken place. See: Decker Eveleth, *People's Liberation Army Rocket Force Order of Battle 2023* (Monterey: James Martin Center of Nonproliferation Studies, 2023), pp. 34-35.

[b] While there is uncertainty regarding the operational status of the DF-21C, analysts have suggested that some may remain at the bases listed above. See: Hans M. Kristensen and Matt Korda, "Chinese Nuclear Forces, 2020," *Bulletin of the Atomic Sciences*, Vol. 76, No. 6 (2020), p. 449 (Table 2); Ma Xiu, *PLA Rocket Force Organization* (Montgomery: China Aerospace Studies Institute, October 2022), p. 145; Eveleth, *People's Liberation Army Rocket Force Order of Battle 2023*, pp. 15, 37n67.

Sources: Ma, *PLA Rocket Force Organization*, pp. 59-166; Eveleth, *People's Liberation Army Rocket Force Order of Battle 2023*, pp. 34-46

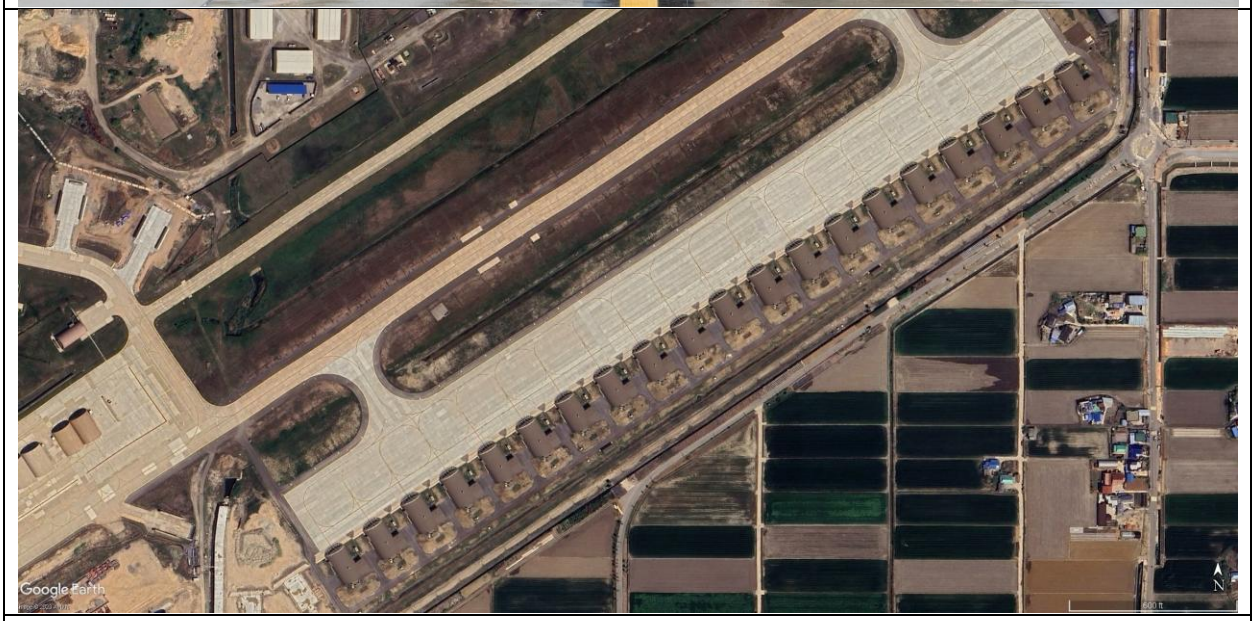
We model missile attacks on two different types of targets on the air bases: hardened aircraft shelters and aircraft parked in the open. We don't include missile attacks on runways in our analysis, for reasons we explain below. The first important target type for the PLARF are hardened aircraft shelters. Hardened aircraft shelters—or HAS—are large, steel-reinforced concrete hangars that protect military aircraft from attack. While some are built into hillsides or underground, most are free-standing, semi-cylindrical structures with

heavy steel doors that are usually sized to fit a single fighter aircraft (see Figure G1, below). Modern HAS are well lit, temperature controlled, and have exhaust ventilation systems, extensive maintenance capabilities, and even allow for internal aircraft refueling (see Figure G2, below). While HAS provide protection from smaller ordnance, such as the bomblets in cluster munitions, a direct hit from a modern penetrating, unitary warhead would severely damage the shelter and likely destroy any aircraft inside. In our analysis, the PLARF targets HAS with ballistic and cruise missiles carrying unitary warheads, aiming to damage the shelters and destroy any aircraft within. The second important target type is open-parked aircraft. In our analysis, the PLARF target aircraft parked in the open using ballistic missiles carrying submunitions aiming to blanket parking areas with explosives and damage and destroy the aircraft parked there.

Figure G1: Hardened Aircraft Shelters at Kadena and Seosan Air Bases

Note: Examples of freestanding HAS at Kadena Air Base, Japan (upper) and buried HAS at Seosan Air Base, Republic of Korea (lower). These images were generated by the authors using Google Earth Pro.

Figure G2: Modern Hardened Aircraft Shelters at Kunsan Air Base



Note: Head-on (upper) and satellite (lower) images of modern hardened aircraft shelters at Kunsan Air Base, Republic of Korea. The satellite image was generated by the authors using Google Earth Pro. Upper image source: Tech. Sgt. Will Bracy/U.S. Air Force, https://www.pacaf.af.mil/News/Photos/igphoto/2002471426/.

Missile Deployment & Allocation

As noted above, the model envisions the PLARF firing missiles with two different types of warheads: unitary warheads aimed at hardened aircraft shelters and warheads carrying submunitions aimed at aircraft parked in the open. Two strategic conundrums China faces are where to deploy its missiles and which missiles should be armed with unitary vs. submunition warheads.[42] With respect to missile location, we divide missiles of a given type evenly between the brigades that operate that type of missile.[43]

The more difficult part of the question is which of its missiles China arms with unitary vs. submunition warheads. We assume the PLARF must make this decision in peacetime, before it knows which regional air bases the U.S. Air Force is going to use in a given conflict. The model automatically distributes PLARF unitary warheads among its various missile brigades according to the following considerations: (a) the total number of unitary warheads available to China, (b) the proportion of "relevant" HAS that are in range of the PLA missiles at a given brigade, and (c) the number of other PLA brigades that have missiles with sufficient range to target those same HAS.[44]

[42] We assume that any of China's missiles, with the exception of DF-26s, can be armed with either unitary or submunition warheads. Because of its low accuracy (see Table D2), the land-attack variant of the DF-26 can only be armed with a submunition warhead. Note that in the excursions that consider the effects of improved-accuracy DF-26s we allow the missiles to be armed with unitary warheads.

[43] For example, China has 96 DF-16a missiles, which are deployed at two missile brigades (see Table G1). We assign 48 of its DF-16a missiles to each of the two brigades.

[44] By "relevant HAS," we mean those HAS in the theater that the PLARF expects the U.S. *might* use during a war—and hence which the PLARF must deploy unitary warheads to target if necessary. For example, in our baseline runs of the model, we assume that the PLA organizes its missile forces to target the HAS in Japan and the Philippines, but not to cover the numerous HAS in South Korea because Seoul has strongly implied it will not permit U.S. forces to fight China from ROK territory. Thus, by assuming that South Korean HAS are not relevant in our scenarios, the model distributes PLARF unitary warheads more efficiently to target shelters in other locations. The model allows a user to toggle on and off South Korean, Japanese, Philippine, and other bases in the region to account for changing geopolitical relationships, which then automatically updates PLA unitary warhead deployment patterns.

The way this happens in the model is that the user makes an initial decision of how many missiles—across the entire theater—will be earmarked to strike hardened aircraft shelters and, therefore, must be armed with unitary warheads.[45] The model takes this input and compares it to the total number of relevant HAS in the theater to determine what the user intends in terms of unitary-warhead missiles available per HAS.[46]

The model then automatically sorts all PLARF missile brigades (see Table G1) according to how many airfields in the region with HAS the missiles at that PLA brigade can reach given the missiles' range. The model ranks these bases from the PLA brigade whose missiles can reach the fewest air bases with HAS, to the PLA brigade whose missiles can reach the most. The model then moves from PLARF brigade to brigade, *in this order*, and assigns unitary warhead missiles to each brigade on the basis of (a) how many HAS the missiles at that brigade can reach, (b) how many other PLARF unitary warheads have already been earmarked to strike those same HAS, and (c) the implied maximum unitary warheads per HAS that the user had selected, as described above.[47] Once this is complete, the model then has the number of unitary warheads deployed to each PLARF missile brigade, and any other missiles at those brigade locations are assumed to be armed with submunition warheads.

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[45] When we conducted our analysis, we adjusted the total number of PLARF missiles targeting HAS (and therefore carrying unitary warheads) up and down and tracked how total U.S. aircraft losses varied to determine a roughly optimal distribution of unitary and submunition warheads from China's perspective. Thus, our main results reflect this optimal distribution of warheads.

[46] For instance, if the user inputs 350 as the number of missiles targeted at HAS, then the model divides this by the total number of relevant HAS in the theater. If this was, say, 70 HAS, then it would imply that the user wants to dedicate approximately 5 missiles to each HAS in the theater (350/70 = 5).

[47] By sorting the PLARF brigades from those that can reach the fewest bases with HAS (which are the least flexible PLARF brigades) to those that can reach the most airbases (the most flexible brigades), and assigning unitary warheads in that order, we roughly optimize China's warhead assignment, because the most flexible bases—by coming last—are able to compensate for the inefficiencies in warhead assignment caused by other PLA brigades, which only have the range to strike the HAS at a few regional air bases.

The next step is to allocate missiles at each PLARF base to actual targets, which depends on the wartime deployment of U.S. forces across the theater.[48] In order to do so, the model again sorts all PLARF missile brigades; this time the sorting is according to how many *in-use* U.S. airbases with HAS the missiles at that brigade can reach, again, going from the least to the most. The model allocates the PLARF's unitary missiles to target the HAS on in-use air bases that are within range of a given PLARF brigade's missiles, in proportion to how many HAS are at each base. By starting the allocation with the PLARF missile brigade that can reach the fewest HAS and working its way toward the PLARF missile brigade that can reach the most, the model allows the most flexible PLARF brigades to assign their weapons to "even out" the distribution of missiles as much as possible, so that each HAS gets roughly the same number of strikes.

This process is repeated for submunition-carrying warheads aimed at parking areas: the model allocates the PLARF's submunition missiles to target parking areas on in-use air bases that are within reach, in proportion to the size of the parking areas, and starting with the PLARF missile brigade that can reach the fewest parking areas and working its way toward the PLARF missile brigade that can reach the most. It does this until the number of missiles targeted at parking on in-use air bases is as proportional to the size of the parking areas on those air bases as possible. Once this process is complete, the model has worked

[48] The underlying logic of the model is that (a) in peacetime China knows which regional bases the U.S. is preparing for possible use, but it does not know what actual deployment strategy the USAF will adopt if a conflict erupts; then (b) when a conflict erupts, China, in most cases, identifies which bases the United States is actually using. By distinguishing the information available to the PLA in peacetime and in conflict, the model has more realism and it captures important uncertainty between these two different stages. Specifically, the model allows users to experiment with novel U.S. regional deployment strategies, which derive their value by forcing China to deploy unitary warhead across the theater to cover HAS throughout the region, but then deploy in wartime into one part of the theater and thus negate the mis-deployed missiles. The model allocates missiles slightly differently under ACE, which is discussed in the section on ACE below.

out the share of unitary vs. submunition warheads at each PLARF brigade (step 1) and the number of missiles from each PLARF brigade allocated to targets on in-use U.S. air bases (step 2).

The final step in the process of missile allocation is the decision of how many days over which these missiles are fired at their targets on in-use air bases. This is comparatively simple: it is a model input that the user chooses. As a baseline, we assume that the PLARF aims to focus its missile strikes on air bases over the course of the first 10 days of the conflict.[49] With this input, the number of missiles allocated to targets on in-use air bases are divided evenly by day over the number of days selected by the user.[50] This then allocates missiles by day to targets on in-use air bases, where they have their effects on U.S. air operations.

Missiles Attacks on Hardened Aircraft Shelters (HAS)

Estimating the effects of missile attacks on hardened aircraft shelters combines data on the missile's accuracy and the target's size to determine the probability of striking the target—what is known as the "single shot kill probability" (SSKP). It uses the following formula:

[49] In the scenarios we examined USAF forces are assumed to be fully deployed to the theater at the start of the conflict. In those scenarios, it is likely beneficial for China to fire the missiles it plans to employ relatively early in the conflict (e.g., over the first 7-14 days) because US aircraft destroyed early in the conflict will have less chance to affect the battle before they are destroyed.

[50] The model places two additional constraints on the day-by-day allocation of missiles to airfields. First, the model only allows each HAS to be struck once per day. So, if the number of missiles allocated to HAS at a given base divided by the total number of days over which they should be fired exceeds the total number of HAS at that base, then the model extends the HAS attacks beyond the number of days selected by the user. For instance, if there was a base that was allocated 50 missiles to be fired at HAS over 10 days but it only has four HAS, then the attacks could go beyond 10 days, since 50 missiles / 10 days = 5 HAS attacks per day, which exceeds to total number of 4 HAS on the base. Second, the model only allows up to ten missiles to be allocated to parking areas per base per day. So, for instance, if a single air base was targeted with 150 missiles targeted on parking over 10 days, the attacks would go beyond 10 days, since 150 missiles / 10 days = 15 parking attacks per day, which exceeds the limit of 10 parking attacks per day. The additional missiles would be fired at the base beyond the 10 days set by the user. In practice, firing more than ten missiles at the parking area of a given airbase in a single day is likely inefficient because the submunition footprints of the missiles would likely overlap, hitting the same aircraft many times.

$$SSKP = 1 - 0.5^{\left(\frac{LR}{CEP}\right)^2}$$

The CEP, or circular error probable, is the median miss distance of the missile, a standard measure of missile accuracy. As shown in Table D2, as a baseline assumption, we credit the PLA's short- and medium-range ballistic missiles with a CEP of 20 meters, its intermediate-range DF-26 with a CEP of 150 meters, and its ground- and air-launched cruise missiles with a CEP of 10 meters.

The LR, or lethal radius, is the distance from the aimpoint that the missile can impact and still destroy its target. We assume that HAS must be physically struck by a missile carrying a unitary warhead in order to destroy them, so the distance from the center of the HAS to its edge is the lethal radius in this case. From a birds-eye view, most HAS are roughly rectangularly shaped, with short and long dimensions (see Figures G1 and G2, above), so for our LR measure, we take the average of the two dimensions and divide it in two. We inventoried and measured each and every HAS in our collection of bases and took a weighted average of each base's HAS lethal radius.[51] The values of each base's "weighted average HAS lethal radius" range from as low as 10.5 meters (Yecheon Republic of Korea Air Force base or ROKAF) to as high as 15.5 meters (Seosan ROKAF). Having these base-specific measures assures that the calculations for the effects of missile attacks on HAS are as accurate as possible for each base.

As noted above, we account for PLARF missile reliability, which we assume to be 90%. We also consider the effectiveness of missile defenses on and around U.S. bases. Because

[51] For example, the 15 HAS at Kadena Air Base (see Figure G1, above) are all approximately 37 meters by 24 meters. The target radius or lethal radius for this base, therefore, is 15.25 (((37 m. + 24 m.)/2)/2). For bases that have HAS of varying dimensions, we calculated the target radius for each variant and then calculated the average across the variants, weighted by how many HAS of each type exists at a base.

ballistic missiles travel at speeds of up to Mach 20 (24,700 km/hr.) whereas cruise missiles travel at much slower speeds (800-900 km/hr.), we assume different intercept rates for these two types. As a baseline, we assume that the PLA's ballistic missiles are intercepted 30% of the time, whereas its cruise missiles are intercepted 80% of the time.[52] Missile reliability estimates and the intercept rate are multiplied by the SSKP formula presented above to produce the probability of destroying a single HAS with a single missile.[53] Multiplying this percentage by the number of missiles fired at a given base on a given day indicates how many HAS have been destroyed on that base that day.

The calculations laid out so far allow us to estimate the probability of destroying HAS, but not necessarily the aircraft inside, which requires two additional considerations. The first is the HAS occupancy rate. If a given base has more HAS than fighter aircraft stationed there, then the occupancy rate of the HAS will be less than 100%. We assume in our

[52] This estimate for cruise missile intercepts seems reasonable given what we've observed in the War in Ukraine. According to analyses by the Center for Strategic and International Studies (CSIS), Ukraine used Western air defense systems such as the IRIS-T to intercept between 75% and 90% of incoming Russian cruise missiles between October 2022 and January 2023, and these rates persisted with the introduction of Patriot missile defense batteries into 2023. See: Ian Williams, *Putin's Missile War: Russia's Strike Campaign in Ukraine* (Washington: Center for Strategic and International Studies, May 2023), pp. 20-24; Ian Williams, "Russia Isn't Going to Run Out of Missiles," Center for Strategic and International Studies (28 June 2023), https://www.csis.org/analysis/russia-isnt-going-run-out-missiles. Note also that a previous analysis assumed a similar, 75% intercept rate for cruise missiles. See: Shlapak, et al., *A Question of Balance* p. 59. Our estimate for ballistic missiles is much harder to assess. On the one hand, ballistic missile should be more difficult to intercept than cruise missiles because of the speed at which they travel. On the other hand, evidence from recent conflicts shows ballistic missile intercept rates to be surprisingly high. For instance, in Ukraine, modern missile defense systems shot down a reported 79% of Russian ballistic missiles in May and June 2023 (Williams, "Russia Isn't Going to Run Out of Missiles."). And when Israel was targeted with Iranian ballistic missiles in April 2024, its missile defense systems may have intercepted as many as 51 of 60, or 85% (Israel was reportedly targeted with 120 ballistic missiles, half of them reportedly failed to successfully launch or reach the target area, and only nine impacted the ground. See: Yaroslav Trofimov, "Analysis: Israel Repelled Iran's Huge Attack. But Only With Help from U.S. and Arab Partners," *The Wall Street Journal* (14 April 2024), https://www.wsj.com/world/middle-east/analysis-israel-repelled-irans-huge-attack-but-only-with-help-from-u-s-and-arab-partners-a7844065; "U.S. Reports: Half of Iranian Ballistic Missiles Failed, Aircraft Damaged in Israeli Air Force Base; UAE, Saudis Shared Intel," *Haaretz* (15 April 2024), https://www.haaretz.com/israel-news/2024-04-15/ty-article/u-s-sources-half-of-iranian-ballistic-missiles-failed-idf-aircraft-damaged/0000018e-e0d0-d7e5-a1fe-e7d1bf3a0000).

[53] Note that we actually multiply the formula by one minus the intercept rate (so 1-0.3, 1-0.8), so mathematically it is more like a "penetration rate" than an intercept rate.

analysis that the PLA doesn't have specific intelligence about how many and which HAS are occupied, which seems realistic given that they'd mostly be relying on ISR (intelligence, surveillance, and reconnaissance) satellite imagery, at best. Second, the aircraft that are parked in these HAS are not always on the ground, as they are often engaged in the sweep mission over Taiwan or in defensive counter air missions over their bases. One of the outputs of the sortie rate analysis presented above is the percent of the time aircraft will be on the ground at a given base in a 24-hour period.[54] Therefore, the occupancy rate of HAS at the base in question (which, as a baseline, we assume to be 100%), along with the percent of time aircraft will be on the ground, are also multiplied by the SSKP formula to estimate the number of HAS-parked aircraft that are destroyed by the missiles fired in a 24-hour period.[55] It is also important to note that there may be times when HAS are destroyed faster than their assigned aircraft, since the aircraft may be flying sorties a good portion of the time. When this occurs, the aircraft previously assigned to now-destroyed HAS get automatically reassigned to be parked in the open.

In our sensitivity analysis, we also consider the effects of counter-ISR by the United States with respect to hardened aircraft shelters (see Appendix B, above). A key capability for the PLARF in these cases is what is known as battle damage assessment (BDA), or the

[54] This is the value of "ground time" divided by 24 hours in the sortie rate formula presented above (see Appendix E). Note that this will vary by base and by mission, from a high of 90% of the time (for aircraft assigned to defensive counter air missions) to a low of about 60% of the time (for more distant bases flying longer sorties to Taiwan).

[55] To illustrate, if a ballistic missile with a CEP of 20 meters is targeting a HAS with a radius of 13 meters, the baseline probability of striking that HAS is 25.4% ($1 - 0.5^{\left(\frac{13}{20}\right)^2} = 0.254$). When missile reliability (90%) and ballistic missile defense (30%) are factored in, that percentage falls to 16.0% (0.254 * 0.9 * (1-0.3) = 0.16). Once we account for the fact that aircraft at that base are only on the ground, say, 70% of the time, the percentage falls to about 11.2% (0.16 * 0.7 = 0.112). And if only 3/4 of the HAS are filled on that base, the percentage would fall to about 8.4% (0.112 * 0.75 = 0.084). If 10 missiles are fired on HAS at that base on that day, the expected number of aircraft destroyed would be less than one (0.084 * 10)—i.e., it would be expected to take 12 or more missiles to reliably destroy a single aircraft (12 * 0.084 = 1.008).

ability to assess the extent of physical and functional damage that results from each of its missile strikes.[56] BDA is critical to the efficient application of military force, especially beyond visual range, since it allows for recalibration or retargeting, and helps assure against re-striking targets that have already been destroyed. With respect to HAS attacks, as a baseline, we assume that the PLARF effectively has prefect BDA: that they never attempt to restrike a HAS that has already been destroyed. However, the model allows the user to "turn off" the PLA's BDA capabilities—simulating a circumstance in which, for a variety of reasons, they may not have access to satellite intelligence. It does so by reducing the effectiveness of each missile attack on HAS by the share of the HAS that have already been destroyed.[57]

In sum, using the approach and formulas presented above, we can simulate the destruction of aircraft in hardened aircraft shelters on bases across East Asia on a daily basis. This reduces the number of aircraft that are available for the fighter sweep mission over Taiwan, and thereby increases the opportunity for the PLA Air Force to maintain air superiority over Taiwan on a daily basis.

Missile Attacks on Aircraft Parked in the Open

Estimating the effects of missile attacks on aircraft parked in the open is complicated by several factors. First, air bases differ in the number, dimensions, and shape of their parking areas. Unlike HAS, which are all roughly the same size and shape, there are no two parking areas that are completely alike. Second, there are analytically-complex "edge effects" in

[56] See: *Joint Publication 3-0: Joint Operations* (Washington: Joint Chiefs of Staff, October 2018), GL-7.
[57] For instance, if the PLARF were targeting a base with 10 hardened aircraft shelters and it managed, over time, to destroy 5 of them, with BDA turned off the calculations presented above (see footnote 55) would be multiplied by 5/10 or 0.5. This makes sense: not knowing which, if any, HAS have been destroyed, the PLARF could be acting as if all 10 were surviving, and their missile strikes on the 5 remaining would therefore be half as effective.

which submunition lethal areas may stray beyond the edge of the parking area, only partially landing in the intended area. Third, in cases where multiple missiles are fired at the same parking area, it is possible to have their submunition lethal areas overlap, partially duplicating (and thereby wasting) the effects that each is intended to have.[58] To account for these issues, we use Monte Carlo simulations to estimate the effects of missile strikes on parking.[59]

In order to do so, we first gathered data on the size and dimensions of parking areas at each of the 74 bases in our sample (see Table C1, above).[60] Using this data, we created a Monte Carlo simulation using Microsoft Excel in which the user assigns a chosen number of missiles to the parking areas at a given base. The simulation then goes through the following steps:

1. It assigns an aimpoint within the parking area(s) for each missile, and automatically spaces them evenly when multiple missiles are aimed at the same parking area;[61]
2. It draws a 1 or 0 with a given probability (in our case, 90%) to assess whether the missile(s) functions reliably;

[58] For a detailed discussion of these issues, see: Stillion and Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks*, pp. 61-80 (Appendix A).
[59] This is the approach taken by: Shlapak et al., *A Question of Balance*, pp. 45-50. Note that the supplementary files accompanying the article include the parking area strikes model (.xlsx) that is set up to run the simulations described here.
[60] We simplified the parking area measurements in two ways for analytical purposes: first, by rounding their dimensions to the nearest 5 meters, and; second, by considering all parking areas to be square or rectangularly shaped, even when certain parking areas were slightly irregularly shaped.
[61] The model automatically assigns missiles to parking areas within the base proportional to their area in meters squared. So, for instance, if the user selects four missiles for a hypothetical base with two parking areas, one whose area is 75% of the total and one whose area is 25% of the total, the model will assign three missiles to the larger parking area (4 * 0.75 = 3) and one to the smaller parking area (4 * 0.25 = 1).

3. It draws a second 1 or 0 with a given probability (in our case, 70% for ballistic missiles and 20% for cruise missiles) to assess whether the missile(s) successfully penetrate(s) U.S. missiles defenses;
4. It draws two random numbers for each missile—the miss angle and the miss distance—which, in conjunction with the missile's CEP, determine the actual impact point(s);[62]
5. It identifies all the points on the parking area in question that are within the lethal radius of the missile impact point(s);
6. It calculates the percentage of the points inside the parking area(s) that are within the lethal radius of at least one impact point, and;
7. It conducts steps 1-6 one thousand times and reports the average.

In terms of the inputs, as noted above, we assume that China's missiles function with 90% reliability and that U.S. missile defenses successfully intercept 30% of the ballistic missiles and 80% of the cruise missiles fired. And, as shown in Table D2, as a baseline we assume 20 meters CEP for China's short- and medium-range ballistic missiles, 150 meters CEP for its DF-26 intermediate-range ballistic missile, and 10 meters CEP for its cruise missiles. Following previous analyses, we assume that China's short- and medium-range ballistic missiles, armed with submunitions, will create a circular lethal area with a radius of 138 meters (see Figure G3, below).[63] We assume the DF-26 IRBM will create a lethal area with a

[62] The miss angle is drawn as a uniformly-distributed random number from 1 to 360. The miss distance is drawn as the absolute value of a normally-distributed random number with a mean of zero and a standard deviation of the missile's CEP divided by 0.68.

[63] We assume that the PLARF's warheads are composed of 75% submunitions and 25% dispersal mechanism. For the SRBM and MRBM, this would amount to about 450 kg (600 kg * 0.75) of submunitions. At 0.45 kg each, PLA rockets would be carrying approximately 1,000 submunitions (450 kg/0.45 kg). And with a lethal radius of 138 meters, they would cover a total area of 59,828 m^2 ($\pi * 138^2$). This would mean that each submunition would cover 60 m^2 (59,828 m^2/1,000) or a circle with a radius of 4.4 m ($\sqrt{(60/\pi)}$). See: Stillion

radius of 239 meters and that China's cruise missiles will create a lethal area with a radius of 113 meters.[64]

Thus, the output of the parking area attacks simulation is the expected parking area covered—as a percentage of the total for a given base—by the lethal radius or radii of a given number of missiles with a given accuracy and reliability, and facing a given missile defense intercept rate, on a single day. As with the hardened aircraft shelter analysis, we account for the fact that the aircraft parked in the open are not always on the ground, as they are often in the air, engaged in the sweep or defensive counterair missions. We multiply the number of open-parked aircraft at a given base by the percent of time the aircraft will be on the ground at that base in a 24-hour period[65] to estimate the expected number of aircraft on the ground that day. This figure is then multiplied by the expected parking area covered by the PLA missile attack to estimate how many aircraft are destroyed in the open that day.[66]

Our approach makes two implicit assumptions that it is important to be clear about. First, we implicitly assume that any aircraft that are within the lethal radius/radii of

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and Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks*, pp. xiiin3, 12, 12n5, 14, 15, 78; Heginbotham et al., *The U.S.-China Military Scorecard*, p. 62n58.

[64] For the DF-26, with its up-to-1,800 kg warhead, it would triple the lethal area compared to the SRBM and MRBMs (1,800 kg/600 kg) and so would cover an area of up-to-179,484 m^2 (59,828 m^2 * 3) or a circle with a radius of 239 m ($\sqrt{(179{,}484/\pi)}$). For the cruise missiles (CJ-10, CJ-20, and CJ-100), with their 400 kg warhead, it would reduce the lethal area by about one-third compared to the SRBM and MRBM (400 kg/600 kg) and so would cover an area of up-to-39,885 m^2 (59,828 m^2 * (2/3)) or a circle with a radius of 113 m ($\sqrt{(39{,}885/\pi)}$).

[65] As noted above, this will vary by base and by mission, from a high of 90% of the time (for aircraft assigned to defensive counter air missions) to a low of about 60% of the time (for more distant bases flying longer sorties to Taiwan).

[66] To illustrate, Misawa Japan Air Self-Defense Forces air base (40.702975252, 141.36958768) has a single parking area that is about 1,980 meters long by 180 meters wide. The simulation estimates that five short- or medium-range ballistic missiles—each with a CEP of 20 meters and a lethal radius of 138 meters—would cover about 39% of this parking area with submunitions, assuming 90% missile reliability and 30% missile defense effectiveness. If there was a squadron of 24 fighter aircraft parked in the open and flying sorties from this base, they would be expected to be on the ground about 65% of the time. Therefore, this strike would destroy about 6 open-parked aircraft (24 * 0.39 * 0.65 = 6.1) at Misawa that day.

detonating missiles are either destroyed or put out of action for the duration of the operation.[67] Second, we assume that the PLA doesn't have specific, up-to-date intelligence on what part of the parking areas of these bases hold aircraft at any given time.[68] Instead, they aim for maximum coverage by blanketing as much of the total parking areas as possible with a given number of missiles.

[67] This seems reasonable given that each submunition will cover a circle with a radius of 4.4 m, and previous analyses have assumed that these submunition each have a lethal radius of up to 6 m. (Stillion and Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks*, pp. 12n5, 80n9). M74 submunitions, which are carried by the M39 Army Tactical Missile System (ATACMS), reportedly have an antipersonnel radius of 15m. ("M39 Army Tactical Missile System (Army TACMS)," DOD 101, Federation of American Scientists (2016), https://man.fas.org/dod-101/sys/land/atacms.htm). That said, not every submunition will successfully detonate, though we don't account for this.

[68] This also seems reasonable given that the PLA would be relying on satellite imagery intelligence, at best.

Figure G3: Open-Parked Aircraft at Iwakuni Air Station and Komatsu Air Base with 138-Meter Radius Circles

Note: F-18s parked in the open at Iwakuni Marine Corps Air Station, Japan (upper) and F-15s and other aircraft parked at Komastu Air Base, Japan (lower), both with 138 meter radius circles. These images were generated by the authors using Google Earth Pro.

In sum, using the approach presented above, we can simulate the destruction of aircraft parked in the open on bases across East Asia on a daily basis. This reduces the number of aircraft that are available to fly missions, and increases the PLA Air Force's chances of being able to maintain air superiority over Taiwan on a daily basis.

Missile Attacks on Runways

In our analysis, we have opted against modeling missile attacks that target runways to impede operations at targeted bases. In this case, the PLARF would be using ballistic and cruise missiles carrying warheads with specialized submunitions designed to penetrate and crater runway pavement. The goal with such attacks is to sever the runway so that no aircraft can takeoff or land until debris and ordnance have been cleared, and craters in the runway have been repaired. Thus, these attacks would aim to impede operations and reduce the sortie rate but would not actually destroy aircraft.

We exclude such attacks from our main analysis because our calculations suggest they are, in most cases, significantly less effective than parking area attacks, and are also less effective than HAS strikes. Counter-runway attacks demand large numbers of missiles for a small and temporary payoff. There may be a few circumstances in which runway strikes make strategic sense, perhaps when facing an adversary with relatively few rudimentary airbases (or very poor runway-repair capabilities), but in Maritime East Asia there appear to be significantly greater U.S. vulnerabilities.[69]

To illustrate the limitations of runway attacks, suppose that the USAF deployed two squadrons of fighter aircraft (approximately 48 aircraft) to Yokota Air Base (near Tokyo , Japan) during a war. Yokota has one long runway, which is 3,555 x 67meters and one major taxiway that could be used to launch and land aircraft if needed, which is approximately

[69] To be clear, if the U.S. and key regional partners do not prepare for runway repair operations—meaning stockpiling necessary equipment and training the repair crews—then counter-runway strikes could play a role in suppressing U.S. airpower. One excellent recent analysis suggests that such preparations are, in fact, lacking; if true, then plugging that vulnerability should be a top priority. On counter-runway strikes, see Kelly A. Grieco, Hunter Slingbaum, and Jonathan W. Walker, *Cratering Effects: Chinese Missile Threats to US Air Bases in the Indo-Pacific* (Washington: Stimson Center, December 2024). Our modeling of counter-runway attacks was heavily influenced by Heginbotham, *The U.S.-China Military Scorecard*, pp. 56-62.

2,420 x 42 meters. To prevent their use by fighter aircraft, the runway would need to be severed twice, since the minimum operating strip (MOS)—or minimum takeoff and landing distance—for fighter aircraft is 1,525 x 15 meters.[70] A single cut of the taxiway would prevent it from being used to launch or land aircraft. Three runway/taxiway "cuts" in total, therefore, would prevent operations at Yokota until at least one was repaired.

For each of the required cuts, a strike would need to crater the concrete in a manner that left less than 1,525 meters of useable length and 15 meters of useable width. The PLA would likely employ missiles armed with warheads filled with runway-cutting submunitions; counter-runways warheads, like those used by the PLA, are designed to create a submunition pattern that reaches out approximately 90 meters from the point of detonation.[71] A PLA missile that was *perfectly* delivered and detonated right at the centerline of the runway at Yokota would merely need to cover 18.5 meters of runway to either side of the warhead.[72] Given the missile's 90-meter radius submunition footprint, this appears straightforward; the missile could "miss" by approximately 70 meters and still

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[70] Shlapak et al., *A Question of Balance*, p. 37; Heginbotham et al., *The U.S.-China Military Scorecard*, pp. 56, 57. See also, for fighters: *Air Force Pamphlet 10-219*, Vol. 4, *Airfield Damage Repair Operations* (Maxwell AFB: United States Air Force, May 2008), pp. 70-71. U.S. tanker aircraft have a MOS of 2,134 x 45 meters. See: *Air Force Manual 11-2KC-135*, Vol. 3, *KC-135 Operations Procedures* (Maxwell AFB: United States Air Force, September 2019), p. 55; *Air Force Manual 11-2KC-10*, Vol. 3, *KC-10 Operations Procedures* (Maxwell AFB: United States Air Force, January 2023), p. 20.

[71] These warheads would likely be composed of (by weight) 75% submunitions and 25% for the dispersal mechanism. For the short- and medium-range ballistic missiles, this would amount to about 450 kg (600 kg * 0.75) of submunitions. Runway cutting submunitions are larger than those used for parking area attacks, so at 4.5 kg each, PLA rockets would be carrying approximately 100 submunitions (450 kg/4.5 kg). And with a submunition footprint that extended out to a radius of 90 meters, they would cover a total area of 25,447 m^2 ($\pi * 90^2$). This would mean that each submunition would cover 294 m^2 (29,440 m^2/100) or a circle with a radius of 9.7 m ($\sqrt{(294/\pi)}$), and each penetrating and detonating submunition would create a crater with a radius of approximately 0.75 meters. See: Shlapak et al., *A Question of Balance*, pp. 38-39; Heginbotham et al., *The U.S.-China Military Scorecard*, p. 58. The DF-26, with its up-to-1,800 kg warhead, would triple the lethal area compared to the SRBM and MRBMs (1,800 kg/600 kg) and so would cover an area of 76,341 m^2 (25,447 m^2 * 3) or a circle with a radius of 156 m ($\sqrt{(76,341/\pi)}$). China's cruise missiles, with their 400 kg warheads, would reduce the lethal area by 1/3 compared to the SRBM and MRBMs (400 kg/600 kg) and so would cover an area of 16,965 m^2 (25,447 m^2 * (2/3)) or a circle with a radius of 74 m ($\sqrt{(16,965/\pi)}$).

[72] This is (67 meters – 15 meters – 15 meters)/2.

cover enough runway to prevent air operations.[73] As a result, even moderately-accurate missiles armed with anti-runway submunitions would have a good chance of striking and severing the runway. For the sake of argument, assume as a baseline that PLA missile guidance was *not* jammed or degraded near U.S. bases; with a 20 meter CEP, each PLA missile which successfully arrived at Kadena would have a roughly 99% probability of creating a runway cut.[74] If PLA missiles can easily cut runways (i.e., SSKP = approximately 99%), why is targeting runways an inefficient targeting strategy?

If, as above, we assume 90% missile reliability and 30% interception for ballistic missiles, then the probability of a given missile landing in a targeted area falls to about 62%.[75] And given that all three targets (two cuts for the runway, one for the taxiway) need to be cut to shut down airfield operations, a volley of three missiles would have only a 24% probability of success.[76] Thus, in order to be 80 percent certain of successfully striking all

[73] A targetter aiming at the center of the runway would need to cover a 37-meter-wide zone down the middle of the concrete with submunitions to deny aircraft the 15-meter strip on either side they would need to land. A 37-meter zone implies that a warhead that detonated *perfectly* at the centerline would need to create an 18.5-meter radius of destruction below the detonation to make a successful cut—far smaller than the actual 90-meter radius of the submunition footprint. Even a warhead that missed in a direction that was perpendicular to the runway (the worst case for the warhead) could miss its aimpoint by more than 70 meters and still leave less than a 15-meter wide strip of useable runway for aircraft.

[74] Assuming a 20 meters CEP, the odds that a missile which functions correctly will deliver its warhead within 70 meters is greater than 99% (this is $1-0.5^{(70/20)\text{^}2} = 0.999$). In reality, this illustrative analysis *understates* the actual effectiveness of PLA missiles because it treats the target as circular when in fact it is linear. The calculation used here, which produce a 99% "single shot kill probability," treats some detonations along the length of the runway as "misses" even though they would be close enough to the edge to fully cut the runway. And yet even with this simplification, each PLA missile has a 99% SSKP against a runway. Analysts who wish to avoid our simplification can employ standard rectangular targeting calculations. For an example, see: Joshua R. Itzkowitz Shifrinson and Miranda Priebe, "A Crude Threat: The Limits of an Iranian Missile Campaign against Saudi Arabian Oil," *International Security*, Vol. 36, No. 1 (Summer 2011), p. 187n90.

[75] This is 0.99 * 0.9 * (1-0.3) = 0.624.

[76] This is $0.624^3 = 0.243$.

three of these targets (i.e., cutting the runway and taxiway), the PLARF would have to fire at least 9 missiles.[77] If the PLA sought 90 percent certainty, they would need 12 missiles.[78]

Hitting Yokota with 9-12 missiles would have only temporary effects. Estimates for how long it takes to repair a severed runway vary, from as low as 3 hours to as high as 8 hours.[79] If we give the runway-attack strategy the benefit of the doubt, and assume it takes 8 hours to repair severed runways, then the PLARF would need to repeat this strike three times in order to keep Yokota closed for 24 hours, at a cost of 27-36 missiles.[80] If, on the other hand, we assume it takes only 4 hours to repair severed runways, which is the standard allotment in U.S. Air Force planning documents,[81] then the PLA would need to repeat this strike 6 times over 24 hours to keep the base fully closed, at a cost of 54-72 missiles.[82]

Even at the low estimates for PLA missile requirements, this strategy seems like a poor use of missiles. If China could keep Yokota closed for a day with merely 30 missiles, then the USAF would have lost 48 fighter sorties.[83] In other words, each missile would have

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[77] With three targets that need to be cut, the PLA would need to achieve at least 92.8% probability at each cut point in order to achieve an 80% probability of cutting all three (this is $0.8^{(1/3)} = 0.928$ or $0.928^3 = 0.799$). The formula to calculate the number of missiles required to achieve a given level of certainty is: $\frac{\log(1-desired\ p(success))}{\log(1-p(hit))}$.
In this case, this is: $\frac{\log(1-0.928)}{\log(1-0.624)} = 2.7 \rightarrow 3$. Three missiles fired at each of 3 targets is a total of 9 missiles altogether.

[78] The PLA must produce a 96.5% at each cut point to reach a 90% probability of cutting 3-of-3 targets (this is $0.9^{(1/3)} = 0.965$ or $0.965^3 = 0.899$). Producing that probability at each cut point would require 4 missiles at each, or 12 missiles for the base. This is: $\frac{\log(1-0.965)}{\log(1-0.624)} = 3.4 \rightarrow 4 * 3 = 12$.

[79] Michael Beckley assumes Taiwanese crews can repair cratered runways in 3 hours. See: Michael Beckley, "The Emerging Military Balance in East Asia: How China's Neighbors Can Check Chinese Naval Expansion," *International Security*, Vol. 42, No. 2 (Fall 2017), pp. 85-86. Heginbotham et al., however, assume 8 hours as their baseline. See: Heginbotham et al., *The U.S.-China Military Scorecard*, p. 60.

[80] This is: 24/8 = 3 * 9 = 27 and 24/8 = 3 * 12 = 36.

[81] See: *AFPAM 10-219*, Vol. 4, pp. 117-119, 127, 135 (Table 10.1). See also: *Tri-Service Pavement Working Group (TSPWG) Manual*, 3-270-01.3-270-07, *O&M: Airfield Repair Damage* (Washington: Department of Defense, May 2020), pp. 7-8.

[82] This is: 24/4 = 6 * 9 = 54 and 24/4 = 6 * 9 = 72.

[83] Based on the results of the model, each USAF fighter aircraft deployed to Yokota can generate 1 sortie per day, which is limited by sortie duration, ground maintenance time, and the pace of U.S. operational sweeps.

eliminated 1.6 USAF sorties.[84] On the other hand, each PLA missile armed for and used against parking areas would, according to our simulation results, destroy on average 2% of the aircraft deployed to Yokota. With 48 aircraft deployed there (even accounting for the percent that will be away flying a mission), each missile will destroy approximately 2/3 of an aircraft.[85] If the parking area strike were carried out on Day 1 of the model's 30-day war, that single PLA missile would deny the USAF 20 sorties; on day 15 that attack would deny the USAF 10 sorties.[86] In short, strikes against parking are roughly 6-12 times as effective as strikes against runways.[87] Stated differently, strikes against runways are 8-16% as efficient as strikes against parking.[88] And, of course, the parking area strikes would destroy aircraft that couldn't be used in future conflicts and wars, whereas runway strikes would not.

For these reasons, we decided to leave runway attacks out of our main analysis, but we hope our approach to the problem presented above is helpful to future researchers. And we note that there are circumstances in which counter-runway strikes could be used in combination with other attacks to improve PLA results.

[84] This is 48/30 = 1.6.
[85] Based on the results of the model, aircraft parked at Yokota that are assigned to sweep missions over Taiwan will be on the ground about 70 percent of the time. Therefore, this is 48 * 0.7 * 0.02 = 0.672.
[86] This is 30 * 0.672 = 20.2 and 15 * 0.672 = 10.1.
[87] This is 10.1/1.6 = 6.3 and 20.2/1.6 = 12.6.
[88] This is 1.6/20.2 = 0.08 and 1.6/10.1 = 0.16. Note also that Yokota, with its single runway and single main taxiway, is pretty typical, in the main features that define it as a target for counter-runway attacks. Its very large parking area, however, means that it is *less vulnerable* to counter-parking attacks than most other airfields in the region. Therefore, for most bases, the benefit of counter-parking attacks relative to counter-runway strikes will likely be even greater. Lastly, if missile guidance is jammed at the bases, the consequence for counter-runway attacks will be significant (because the target is relatively small); the consequence for counter-parking attacks will be much smaller.

Missile Attacks Under Agile Combat Employment (ACE)

Our analysis of missile attacks under the Agile Combat Employment (ACE) scenarios involves some additional considerations. Because ACE envisions U.S. air forces trying to use mobility and other means to enhance their survivability, it has important implications for how the PLA will conduct its missile attacks. The key question under ACE is the extent to which the model user envisions the U.S. obstructing the PLA's ISR capabilities. The model includes three settings: none, moderate, and total. When the U.S. is blinding *none* of the PLA's ISR capabilities, it implies that the PLA knows exactly where U.S. forces are at effectively all times, and therefore it wastes none of its missiles by firing on bases without U.S. aircraft. When the U.S. is engaged in a *total* blinding of the PLA's ISR capabilities, it implies that the PLA has no idea where U.S. forces are located at any given time. Under this condition, the PLA is forced to fire its missiles at all bases within the broader deployment set, and therefore it wastes a portion of its missiles by firing on bases without U.S. aircraft. This is modeled by dividing the number of active bases by the number of deployment set bases, and only allowing the PLA to fire this percentage of its missiles. As noted above (see Appendix C), as a baseline we assume there are 40 bases in the deployment set and 20 active bases, so under total ISR blinding, the PLA would only be able to fire 50% of its missiles,[89] with the remainder being assumed to be wasted on bases without U.S. forces present. When the U.S. is blinding a *moderate* amount of the PLA's ISR capabilities, it implies that the PLA knows where some but not all U.S. forces are located. Under this condition, the PLA is forced to fire at some bases that don't contain U.S. forces. In terms of the modeling, we take the average of share of missiles the PLA can fire at bases containing

[89] This is, 20 active / 40 deployment = 50%.

U.S. forces under the *none* setting and under the *total* setting and only allow the PLA to fire that percentage of its missiles. Since under the *none* setting, this is 100% and under the *total* setting this is 50%, as a baseline under the *moderate* setting, we assume the PLA is only able to effectively fire 75% of its missiles.[90] The remaining 25% of its missiles are assumed to be wasted on bases without U.S. forces present.

To sum up, our analysis of ACE involves three basic adjustments to the standard model setup. First, it selects a representative sample of active bases from a broader deployment set of bases, and deploys U.S. aircraft to those bases (see Appendix C). It reduces the sortie rate of U.S. aircraft operating from those bases, depending on how often U.S. forces relocate and how much time is lost by relocating (see Appendix E). And it reduces the number of missiles the PLA is able to effectively fire, depending on how extensive the U.S.'s blinding of PLA ISR capabilities is.

[90] This is, (100% + 50%) / 2 = 75%.

H) Air-to-Air Combat & Fighter Sweep Mission Success

In our analysis, we envision the U.S. Air Force contesting the Peoples Liberation Army Air Force's (PLAAF) combat air patrol (CAP) over Taiwan, and we therefore include an air-to-air model.[91] Given that the mission is to prevent the PLAAF's control of the air over Taiwan, the air-to-air model also allows us to assess the extent to which the U.S. is succeeding in this primary aim.

The air-to-air analysis envisions the PLAAF conducting a defensive counterair mission over Taiwan and the U.S. air force contesting the control of Taiwan's air by a series of offensive counter air sweep operations each day. On the U.S. side, the size of its sweep operations is produced by the sortie generation model (see Appendix E) and dependent upon any attrition that results from People's Liberation Army Rocket Force (PLARF) missile attacks on bases (see Appendix G). On the PLAAF side, we follow previous analyses and assume that China can commit 1,000 fighter aircraft to this mission—400 of which play a purely defensive role over China's territory and 600 of which engage in the counterair mission over Taiwan.[92] We assume that the PLAAF commits all 230 of its 5th generation J-20 fighter aircraft to the counterair mission over the Strait, and that these have the same readiness rate of 70% as U.S. aircraft (see Appendix D).[93] Thus, the PLAAF establishes its CAP with 160 5th generation fighter aircraft and 440 4th generation fighter aircraft. As a baseline, we assume that China sets up three CAP patrols which are 175-250 kilometers off

[91] Our air-to-air model is derived from: Michael J. Lostumbo, David R. Frelinger, James Williams, and Barry Wilson, *Air Defense Options for Taiwan: An Assessment of Relative Costs and Operational Benefits* (Santa Monica: RAND, 2016), pp. 34-48, 98-106.
[92] Heginbotham et al., *The U.S.-China Military Scorecard*, pp. 76, 82. This estimate seems reasonable, given that China is believed to have 1,536 4th and 5th generation fighter aircraft in its arsenal. See: *The Military Balance 2025*, p. 246.
[93] *The Military Balance 2025*, p. 246.

of Taiwan's north, east, and south coasts.[94] We assume China sets up three patrols in order to protect its surface naval fleet and any of its ground forces on Taiwan from U.S. fighter aircraft or cruise missiles approaching the Taiwan Strait from north, the south, or directly over Taiwan's territory. In practical terms, this means that the PLAAF must divide its defensive counterair force in three, since all three CAP stations need to be continuously patrolled. We also assume that the CAP needs to be well beyond Taiwan's coast. This is because of the threat to the People's Liberation Army Navy (PLAN) surface fleet of the U.S.'s air-launched long-range anti-ship missiles (LRASM), which have a maximum range of 370 km.[95] However, because in practice these are rarely fired at maximum range, we assume that the PLA sets up its CAP stations at about 300 km from Taiwan's *west* coast, in order to head off or intercept missile attacks on its surface fleet in the entirety of the Taiwan Strait.[96] Thus, as a baseline we envision PLAAF aircraft taking off from their bases, refueling just off of the Chinese coast, flying 480-560 kms to their CAP stations, flying their CAP missions, and then returning to their bases.[97]

The air-to-air model conceives of aerial combat over Taiwan as a series of smaller, 2-v-2 engagements, in which you have two U.S. fighter aircraft engaging with two PLAAF fighter aircraft.[98] To simplify the analysis, we assume that the pairs of aircraft on each side of the

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[94] Their locations are, northern: 26.0499837419, 124.239724346; central: 23.0213010893, 123.11960385; southern: 20.0023159839, 120.658873576.
[95] "Fast Facts: Long Range Anti-Ship Missile," Lockheed Martin (2020), https://www.lockheedmartin.com/content/dam/lockheed-martin/mfc/documents/business-area-landing/Fast-Facts-LRASM.pdf.
[96] 300 km from Taiwan's west coast was measured at three points—northern (Port of Taipei): 25.1867057506, 121.406970976, central (Taichung Port): 24.2961752434, 120.503237525, southern (Kaohsiung Harbor): 22.6176995479, 120.265663494.
[97] We assume the refueling location is approximately here, 24.7743242904, 118.841748324, which is over the Chinese coast and is within 110 km of three PLAAF air bases (Longtian Airbase, Huian Airbase, and Zhangzhou Airbase). To simplify the modeling, we take the average of the distances between the refueling point and the three CAP points, which is 533 km ((560 km + 480 km + 560 km)/3 = 533 km).
[98] Lostumbo et al., *Air Defense Options for Taiwan*, pp. 37-38, 98.

engagement are uniform in terms their generation,[99] though the model does allow pairs of aircraft of different generations to engage each other.[100] The number of U.S. air-to-air groups available is determined by the number of offensive counter air sorties the U.S. can muster and the number of separate sweeps it conducts on a daily basis. As a baseline, we assume that the U.S. sends two fighter sweep sorties per day to challenge the PLAAF CAP over Taiwan. We limit the size of each U.S. fighter sweep to a maximum of 72 aircraft as a baseline assumption, with 10 percent being dedicated to electronic warfare and/or suppression of enemy air defense (SEAD).[101] On the PLAAF side, we assume that their aircraft fly one sortie per day, that they maintain their defensive counterair mission continuously, and that, as a baseline, they spend 1.0 hours on their CAP station.[102] The number of aircraft they can maintain continuously over Taiwan is divided by three—because of the three CAP stations—and this then determines how many counterair groups of two are available to defend each CAP.

As a baseline, the air-to-air model assumes that 80% of the PLAAF CAP groups over Taiwan choose to engage the incoming U.S. air forces, with the remainder fleeing back toward China in order to fight another day. Each remaining PLAAF CAP group will be engaged by a U.S. fighter sweep group, and the engagements established as follows. First,

[99] Thus, on either side you can only have a pair of 4th generation aircraft or a pair of 5th generation aircraft, not one of each.
[100] The model allows any combination of U.S. 5th generation vs. PLAAF 5th generation, U.S. 5th generation vs. PLAAF 4th generation, U.S. 4th generation vs. PLAAF 5th generation, or U.S. 4th generation vs. PLAAF 4th generation to occur.
[101] Thus, even if the U.S. has 200 offensive counter air sorties available on a given day, if it plans to conduct just two sweeps, then the most it will actually send is 144 (that is, 72 * 2) and the most that would be dedicated to the fighter sweep mission is 130 (144 * 0.9)
[102] This is based on the distance from the refueling point to the CAP station (533 km), an assumed maximum range for their fighter aircraft of 2,000 km, and a cruising speed of 915 km (to match U.S. aircraft). This is: (2,000 km – (533 km * 2)) / 915 km/h = 1.0.

5th generation aircraft groups on both sides are matched up for engagements. Since there can only be one group on each side of an engagement, the number of 5th-on-5th engagements is limited by the side with the smaller number of 5th generation groups. Second, if either side has additional 5th generation groups after the 5th-on-5th engagements are matched up, those remaining 5th generation groups are matched up with the other side's 4th generation groups. Third, the remaining 4th generation groups on both sides are matched up with each other for engagements. Again, since there can only be one group on each side of an engagement, the number of 4th-on-4th engagements is limited by the side with the smaller number of remaining 4th generation groups. After these 4th-on-4th engagements are matched up, any remaining 4th generation aircraft on either side are assumed to not engage in air-to-air combat at that time. Thus, the air-to-air model effectively assumes that both sides put their best aircraft forward whenever possible. For the U.S., this is to lead the fighter sweep mission to Taiwan. For China, this is to defend its CAP stations from the incoming U.S. fighters.

With the number and type of engagements established, the model then makes a series of assumptions about the engagements that generate kills for each side and therefore the attrition that both sides' forces suffer. First, we assume that only 50% of the engagements actually result in air-to-air missiles being fired.[103] Second, we assume that, in the engagements where missiles are fired, the number of missiles each side fires depends upon their own generation and the generation of the aircraft they face, which ranges from 1

[103] We break with Lostumbo et al. with this assumption, since otherwise the rates of attrition generated by the model appeared to be unrealistically high. We assume a 50% engagement success rate for both sides equally, so the assumption doesn't give either side an advantage, but simply slows the rate of attrition in the model down.

missile fired to 4 missiles fired per group. Third, we assume that each of these missiles has a certain probability of hitting aircraft on the other side. This, again, depends upon the groups' own generation and the generation of the aircraft they face, and it ranges from 30% to 70%. Fourth, we assume that the missiles that are close enough to hit aircraft on the other side have a 70% probability of killing the aircraft, which we apply to all engagements. Fifth, we assume that the probability of hitting and killing adversary aircraft is discounted by the probability that the attacker can avoid electronic countermeasures by the opposing side's defensive avionics, which ranges from 22.5% to 65%. All these assumptions are combined into the following equation to estimate losses of aircraft for each side:

$$\#engagements * \#groups * \%fire\ missiles * \#missiles\ fired * p(hit) * p(kill|hit) * p(avoidEA)$$

Sixth, and finally, we assume that PLAAF aircraft suffer 0.5 percent attrition per day due to Taiwan's air defense. Table F1, below, presents the variables values that are included in the baseline run of our analysis. The divergent variable values on each side of the engagements presented in Table F1 are intended to reflect both differences in aircraft technology and in pilot training and skill.

Table F1: Air-to-Air Model Variable Values

	Missiles fired		*P(hit)*		*P(kill|hit)*		*P(AvoidEA)*	
	U.S.	PLA	U.S.	PLA	U.S.	PLA	U.S.	PLA
U.S. 4th vs. PLA 4th gen.	4	2	70%	50%	70%		55%	40%
U.S. 5th vs. PLA 4th gen.	4	1	70%	30%			65%	22.5%
U.S. 4th vs. PLA 5th gen.	2	2	42%	50%			30%	65%
U.S. 5th vs. PLA 5th gen.	2	1	42%	30%			55%	40%

Note: Variable values in first two rows (involving PLA 4th generation aircraft) are from Lostumbo et al., *Air Defense Options for Taiwan*, pp. 100-102. The variable values in these first two rows are the averages of the relevant values presented in Lostumbo et al.'s Tables B.1, B.2, B.3, and B.4 (pp. 100-101), assuming the U.S. operates the F-16C/D and the F-35 and that the PLA operates the J-10, J-11A, J-11B, and the J-16 armed with PL-12s of PL-15s. Note that PLA missiles fired are cut in half to reflect their smaller CAP groups in our scenario. Variable values in second two rows (involving PLA 5th generation aircraft) are based on our own assumptions—since Lostumbo et al. don't have scenarios with a 5th generation Chinese fighter—and are imputed from the values presented in rows one and two.

The equation presented above is applied to each side's force to estimate the daily losses of aircraft in air-to-air combat over Taiwan. On the U.S. side, these losses are applied proportionately to the bases from which they are flown, reducing the number of aircraft remaining for the fighter sweep mission on the following day(s). On the PLA side, combined with attrition due to Taiwan's air defense, these losses come out of the PLA's total force commitment, and leave fewer aircraft for their defensive counter air CAP mission on the following day(s).

The other purpose the air-to-air model serves is to give us a sense of whether the U.S. is succeeding in its mission of preventing the PLAAF from establishing air superiority over Taiwan. To answer this question, the model tracks three key outcomes. The first is the total number of aircraft losses the PLAAF suffers on a daily basis, as described above. Second, the model counts the total number of offensive counterair (OCA) sweep sorties the U.S. is able to fly on a daily basis (see Appendix E). The third outcome measure is the total number of strike sorties the U.S. is able to fly on a daily basis. As noted above, as a baseline we assume that U.S. OCA sweeps consist of 72 aircraft, 10% of which are dedicated to SEAD and EW roles. Of the 65-or-so aircraft that remain, we assume they can be dedicated to the OCA fighter sweep mission or armed with air-to-ground munitions for a strike mission. As a baseline, we assume that the U.S. requires twice as many fighters conducting the OCA sweep mission as the PLAAF has in the air on any of their DCA CAP patrols. Any fighter aircraft beyond this threshold are designated as strike aircraft and are free to target PLA surface forces, including ships, personnel, and other ground targets. Thus, if the U.S. loses aircraft at a lower rate than the PLAAF, the number of strike sorties it can fly will increase over time. And the number of strike sorties the U.S. is able to fly on a daily basis is a good

indication of its ability to contest PLA military operations on the surface, be it a naval blockade of Taiwan or an amphibious assault of the island.

In sum, using the approach presented above, we can simulate the air-to-air losses on both sides resulting from aerial combat over Taiwan on a daily basis. Over time, this reduces the number of aircraft that are available for the fighter sweep mission, and thereby reduces number of U.S. aircraft that can contest the PLA's control of Taiwan's air space. It also provides our key measures of success for the U.S. mission—the losses in the air it is inflicting on the PLA, the number of OCA sweep sorties it is able to fly, and the PLA targets it is able to strike on the surface.