STERG

SOLAR THERMAL ENERGY RESEARCH GROUP

Design of Multicopter for Heliostat Field Cleaning Purposes

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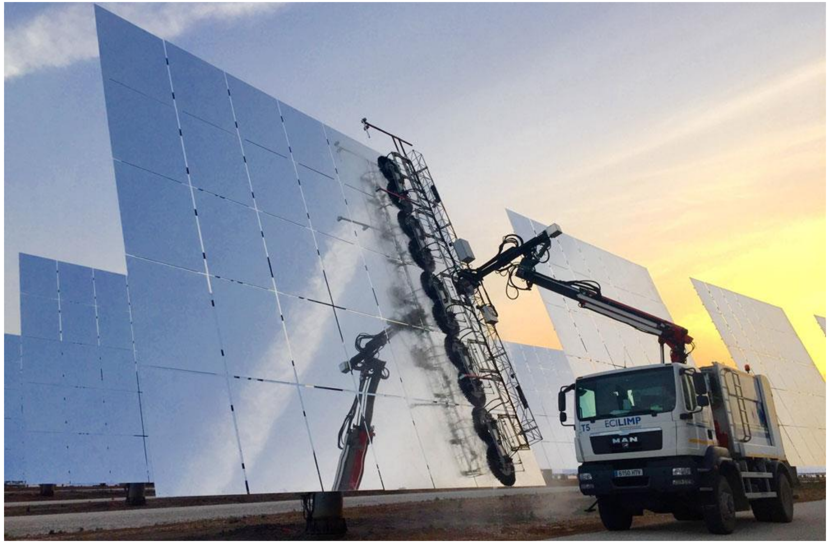
Outline

- Introduction to heliostat cleaning
- Drone selection model
- Application to CSP plant

Heliostat Cleaning

Current methods



Gemasolar plant, property of Torresol Energy, Cleaning Technology property of ECILIMP
Source:https://www.solarpaces.org/marrakesh-conference-presented-solutions-for-reducing-water-use-in-csp/

- Reflectivity is key
- Regularly cleaning
- High amount of water
- Broken mirrors
- Constant manpower

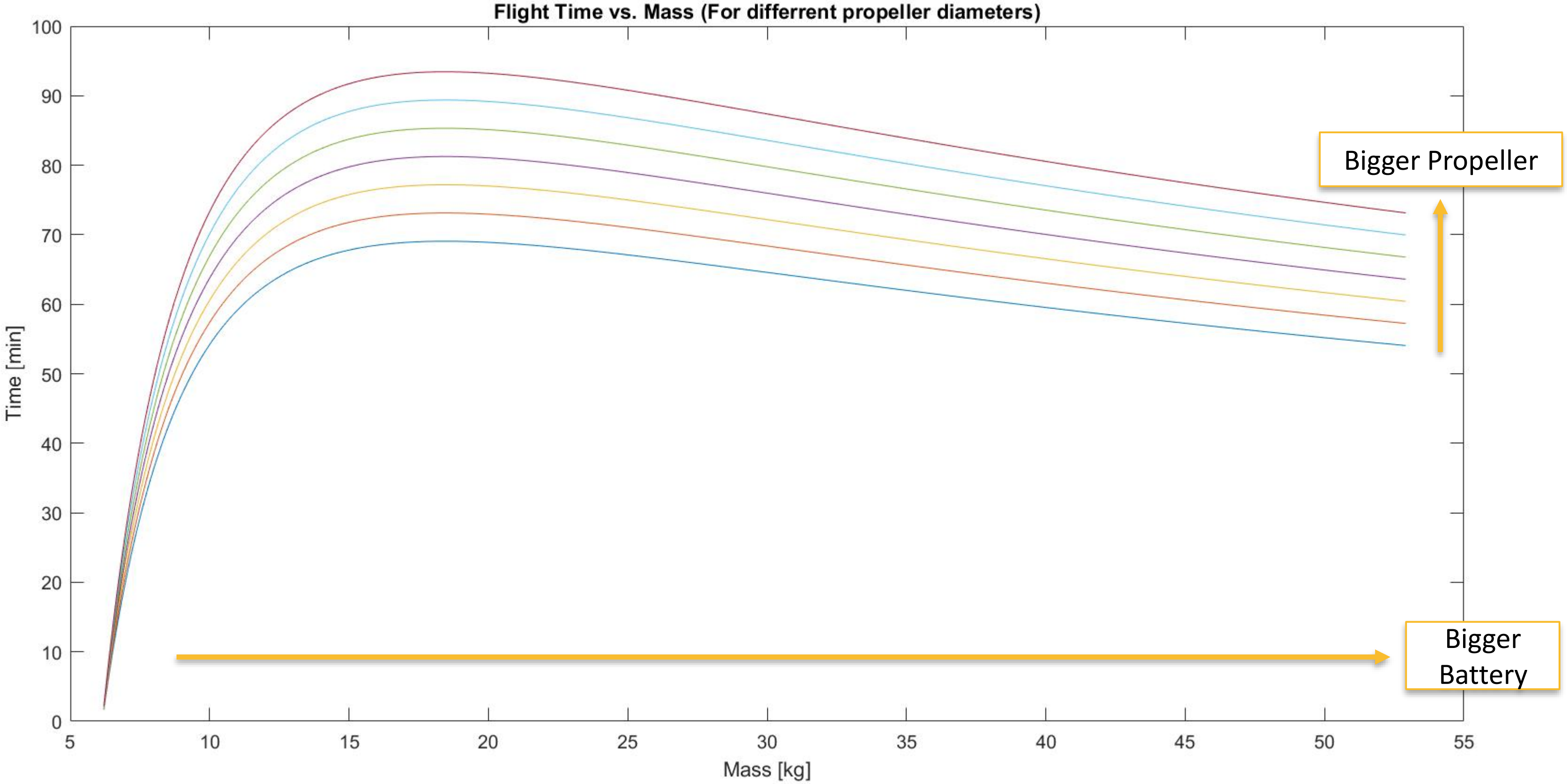
Heliostat Cleaning

Researched method

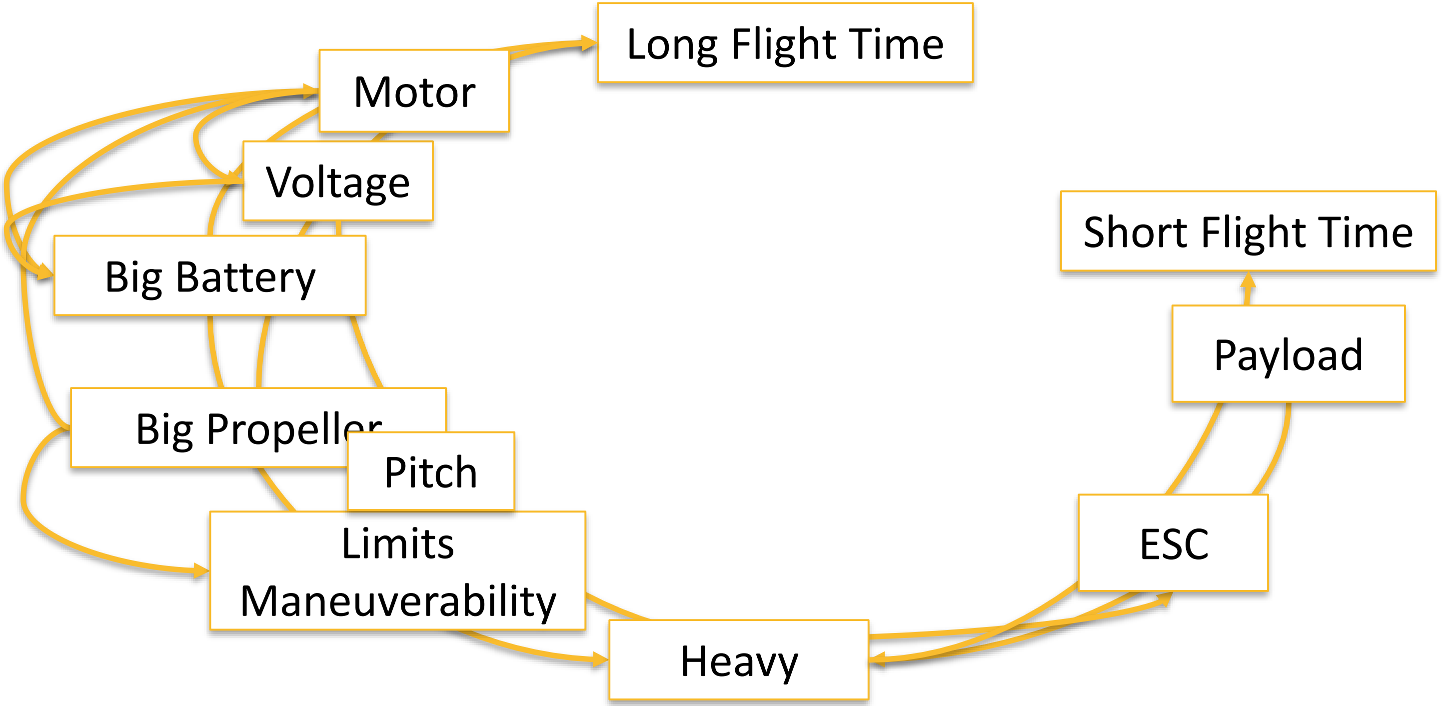
Gemasolar plant, property of Torresol Energy, Cleaning Technology property of SENER
Source: http://www.sener-aerospace.com

- Reflectivity is key
- Cleaning regularly
- Low amount of water (0.03l/m2)
- No broken mirrors
- Maximize cleaning capacity/hour
- Autonomous system
- Direct contact and deep cleaning
- Homogenous cleaning
- No impact on on-site roads

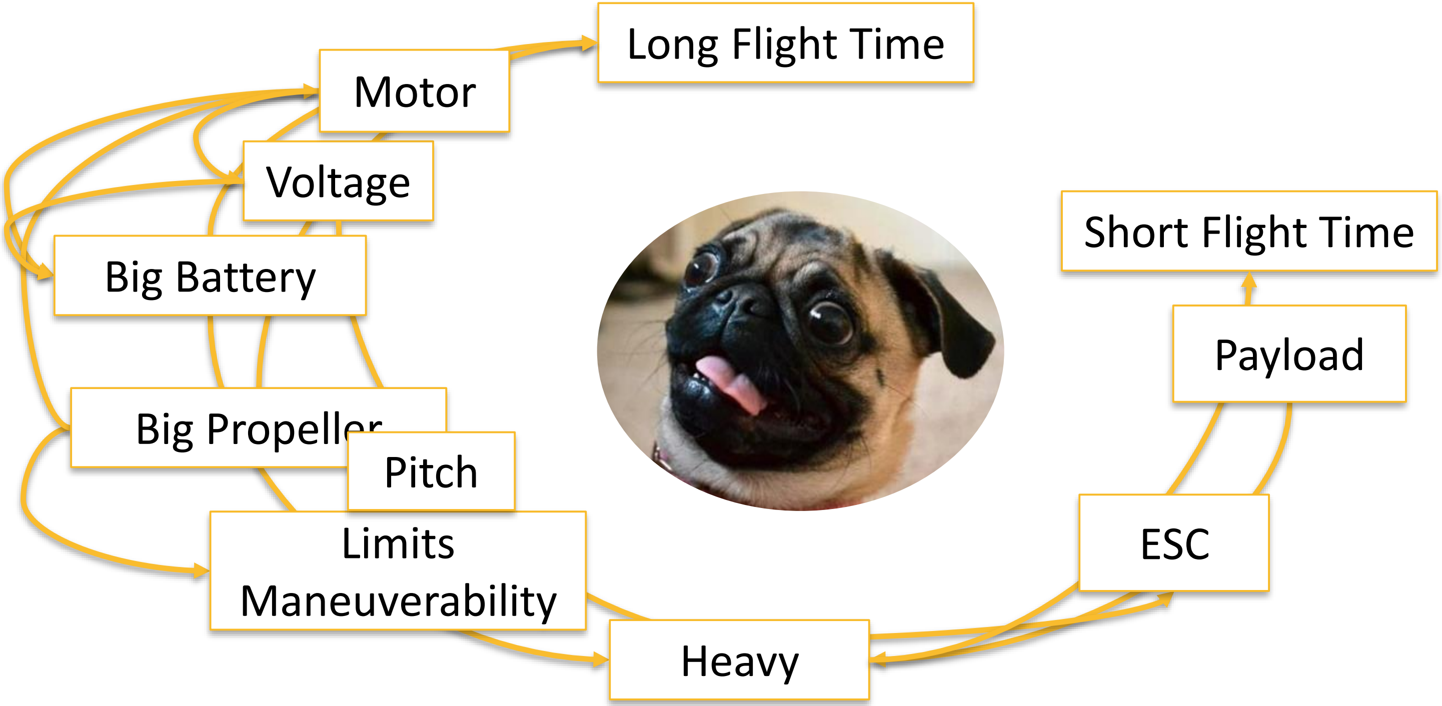
Drone Selection Model



Drone Selection Model



Drone Selection Model



Drone Selection Model

Select a reference drone based on a required **payload.**

- 100 commercial motors with suggested:
  - Propeller
  - ESC
  - Battery voltage
- Plus 50 sizes of batteries

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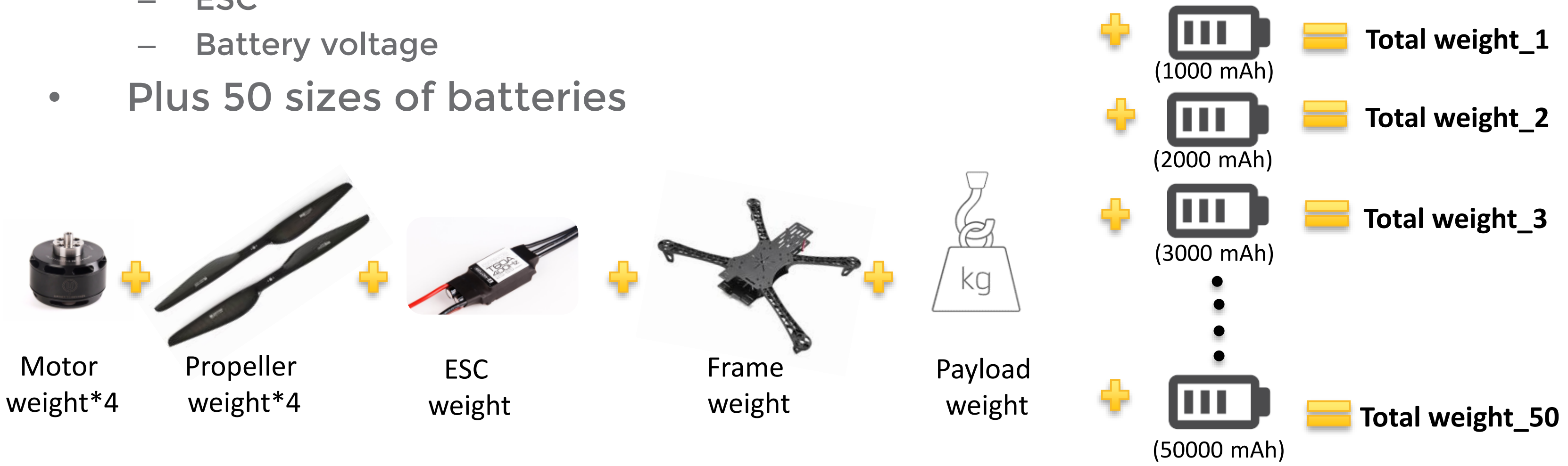
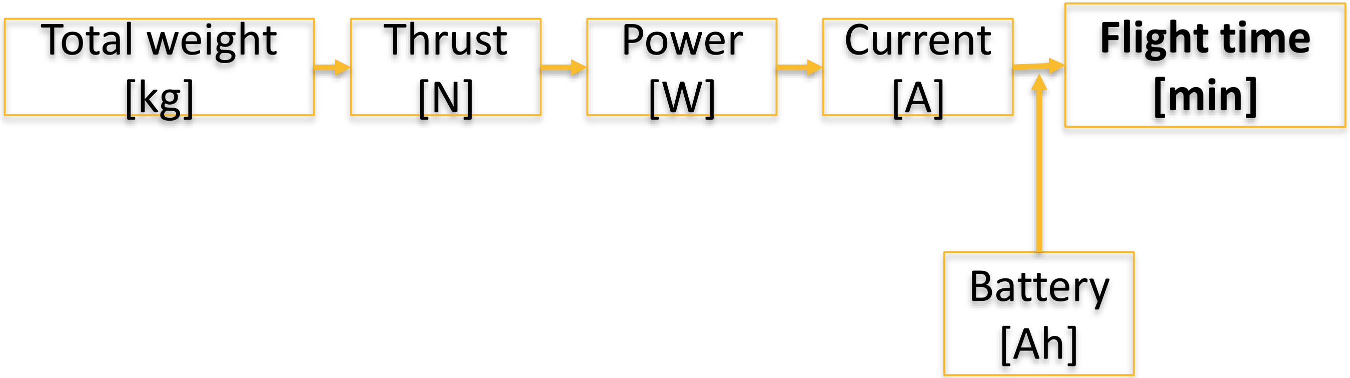


Drone Selection Model

Momentum & Blade Element Theory



Source: Johnson, Wayne. (1994). *Helicopter Theory*.

Drone Selection Model

Configuration with the best flight-time is selected

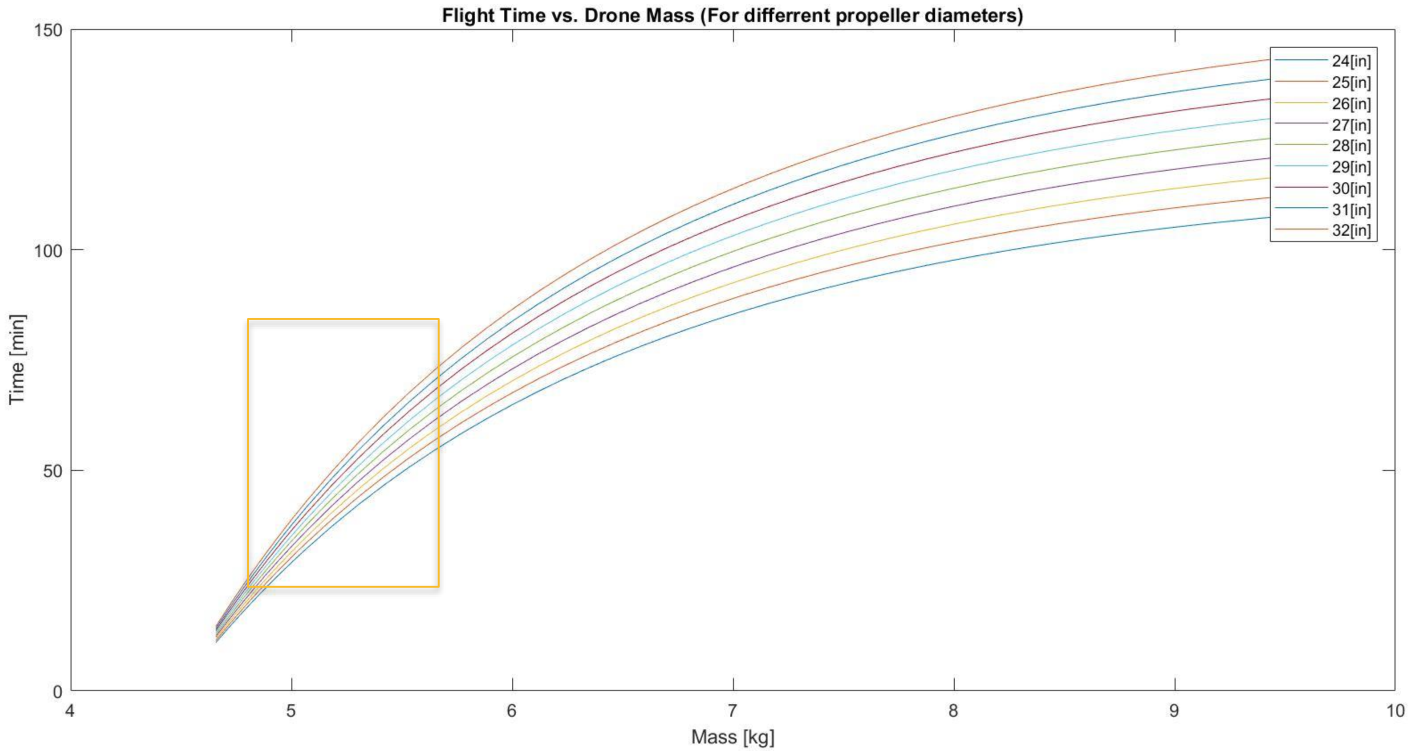
Payload: 2 kg

```
Configuration = 58
Propeller size [in] = 28
Pitch [in] = 9.2
Battery voltage (*3.7 V) =  6
Max thrust [g] = 19516
Drone weight with NO battery [g] = 4334.5
```

Source: Johnson, Wayne. (1994). *Helicopter Theory*.

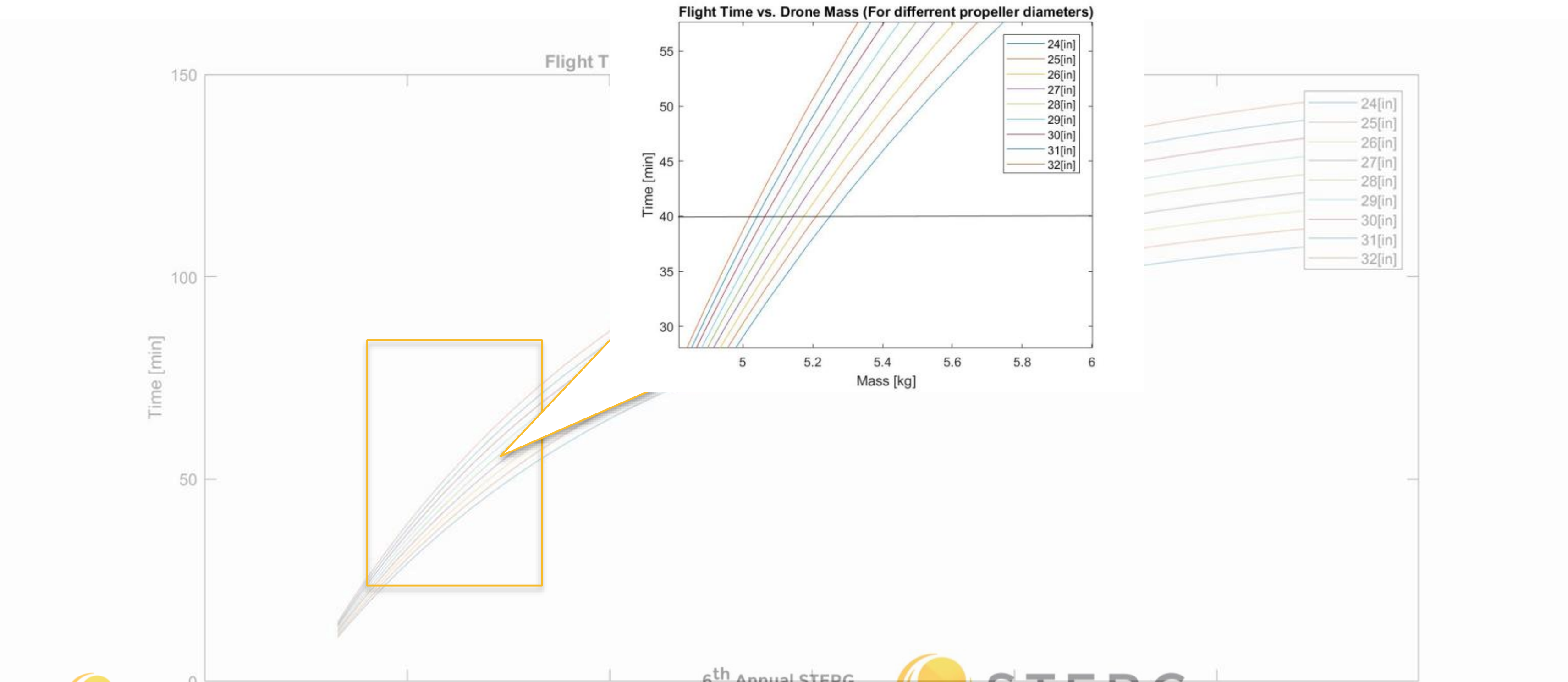
Drone Selection Model

Flight-Time vs. Mass



Drone Selection Model

Flight-Time vs. Mass



Drone Selection Model

Flight time: 40 min / Payload: 2kg

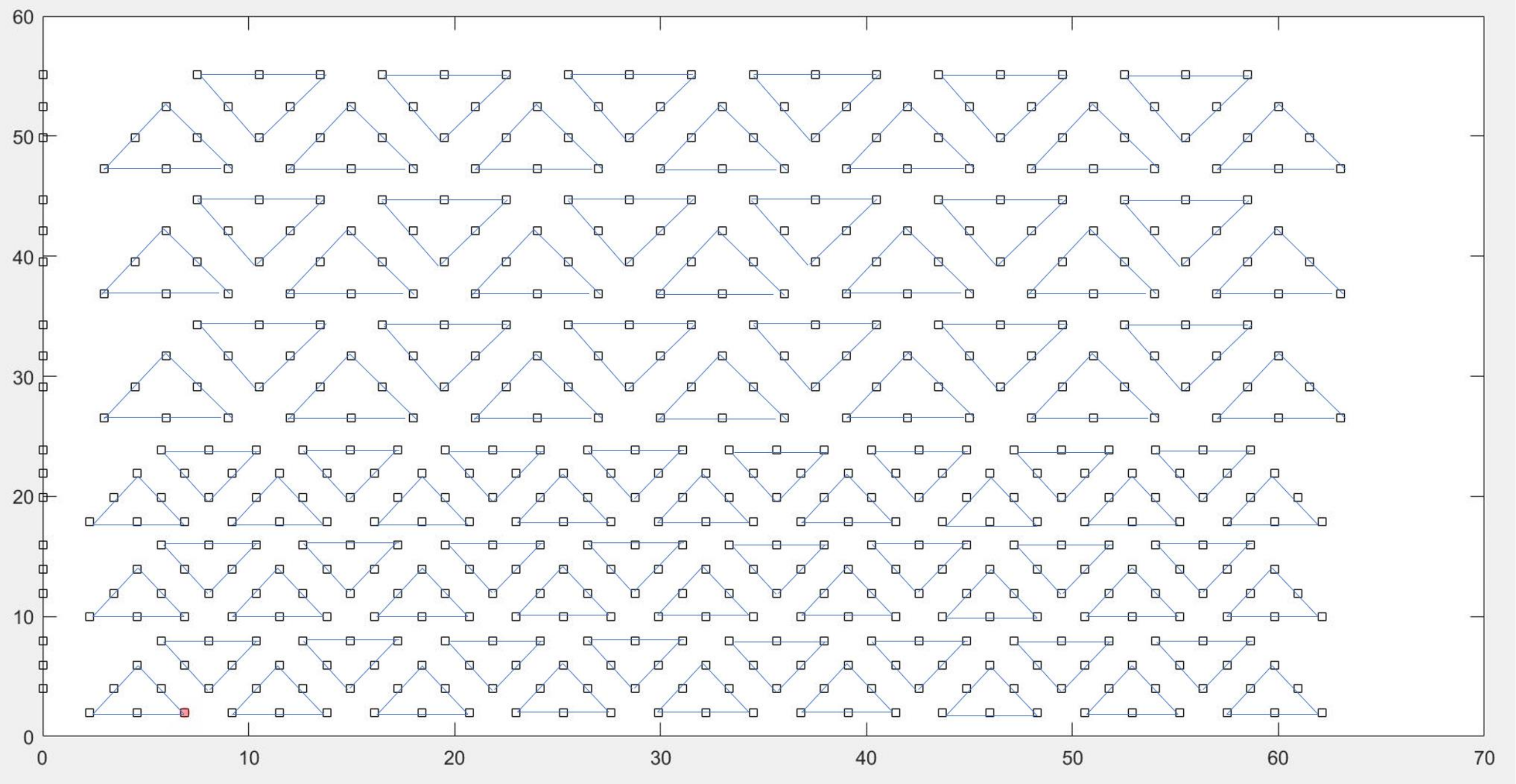
Diameter_in	pitch_in	Batt_Energy_mAh	Batt_Weight_g	AUW_g	RPM	Power_W	Torque_Nm
24	7.7	7000	966	5301	1808	92	0.49
25	8.1	6000	849	5184	1635	86	0.5
26	8.4	6000	849	5184	1515	82	0.52
27	8.7	6000	849	5184	1408	79	0.54
28	9	6000	849	5184	1311	76	0.56
29	9.4	5000	732	5067	1201	71	0.57
30	9.7	5000	732	5067	1124	69	0.59
31	10	5000	732	5067	1055	67	0.6
32	10.3	4500	674	5009	986	64	0.62

Longer flight-time

Lower maneuverability

Application to Heliostat Field

Case study: 540 heliostats field



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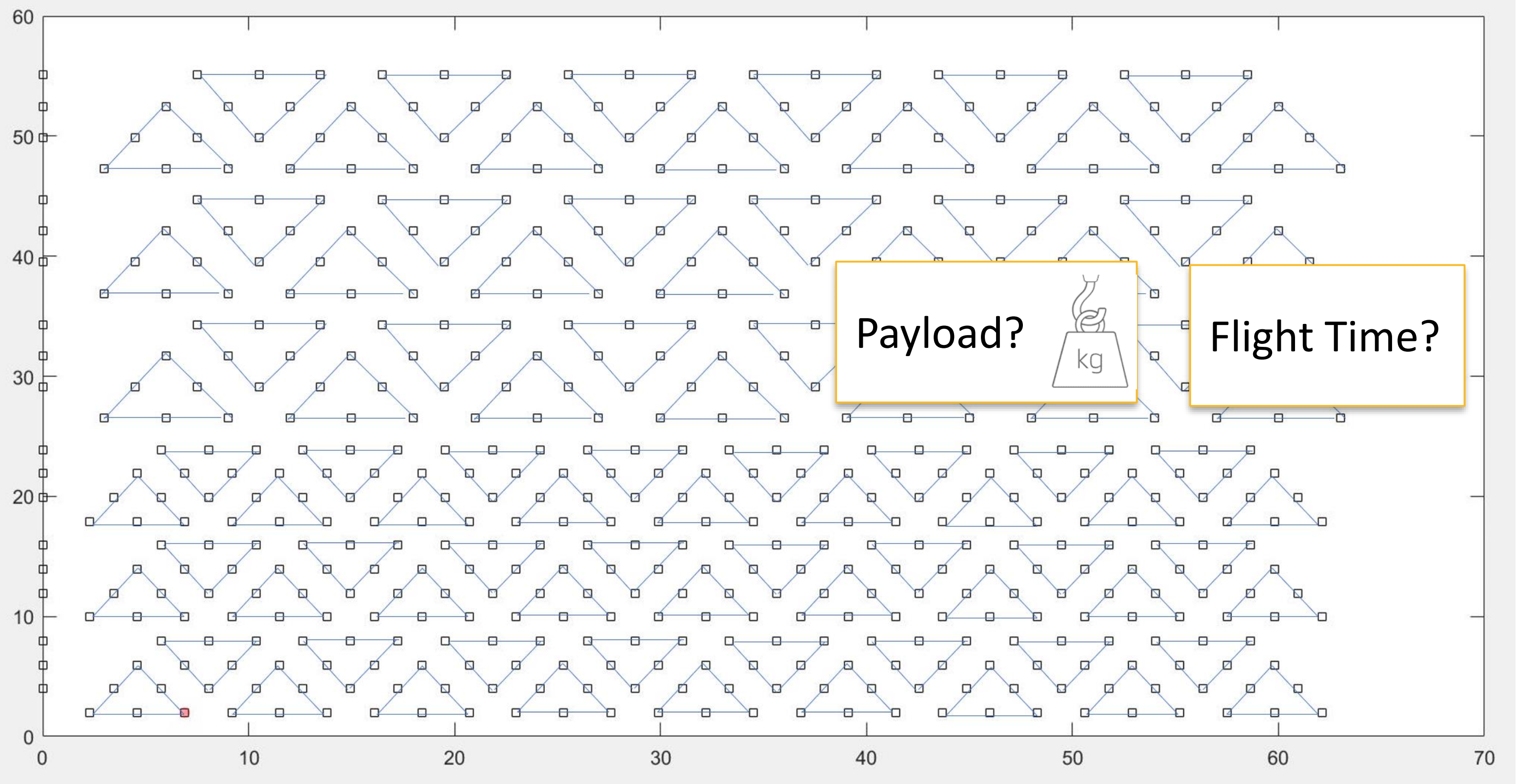
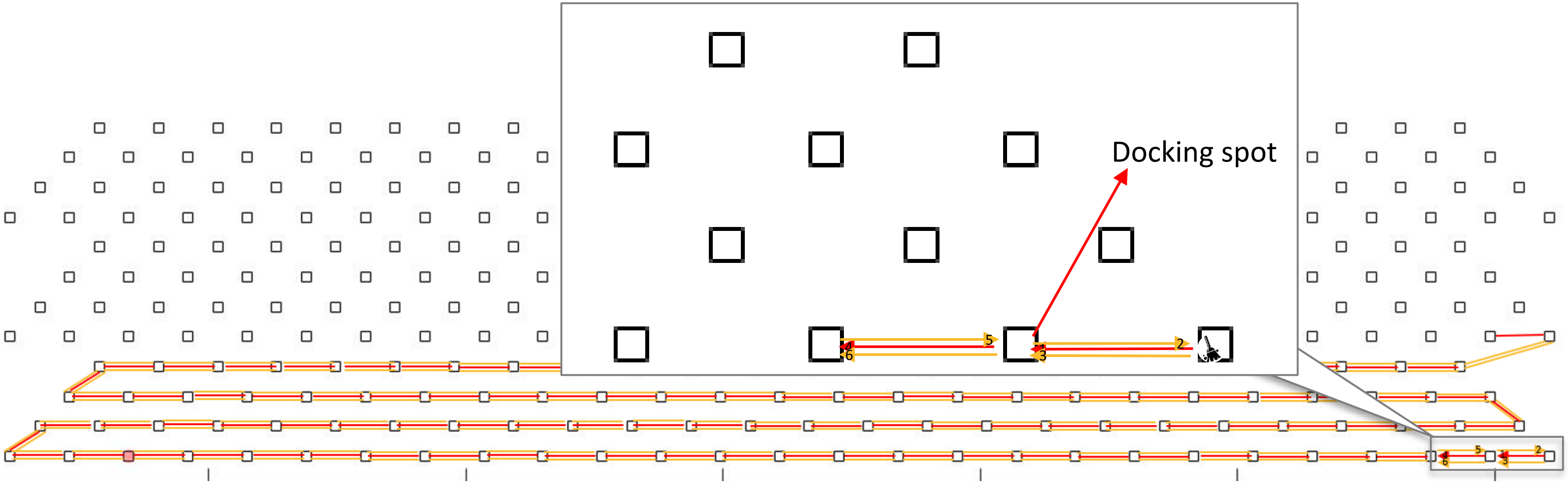


Application to Heliostat Field

Path: 1 cleaning device



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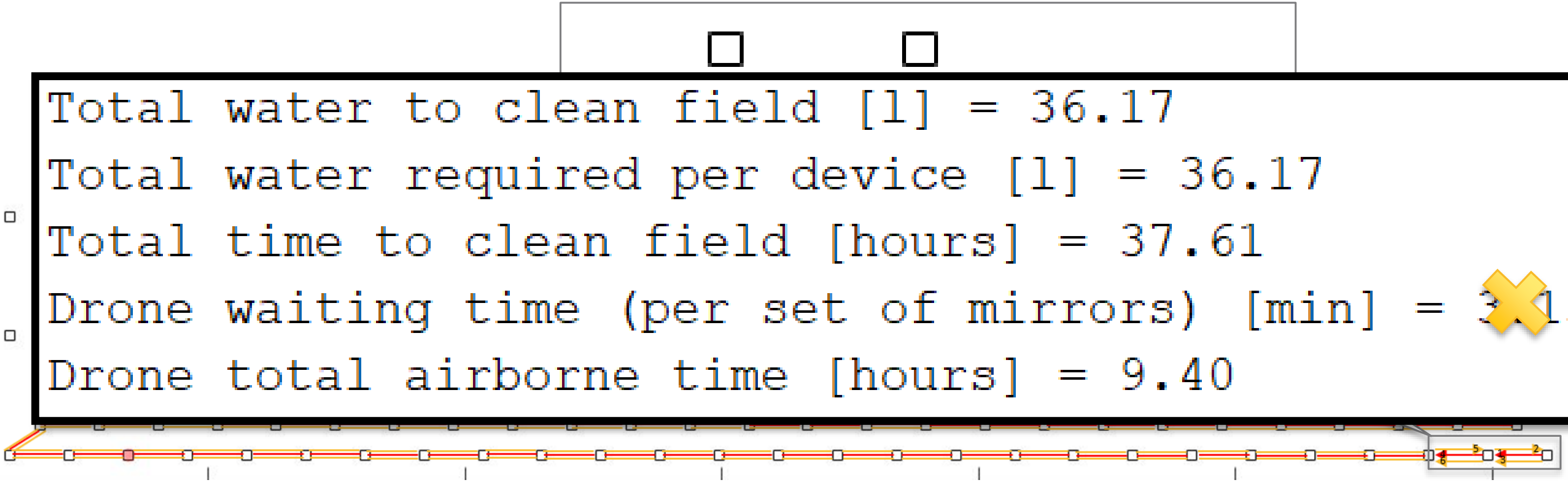
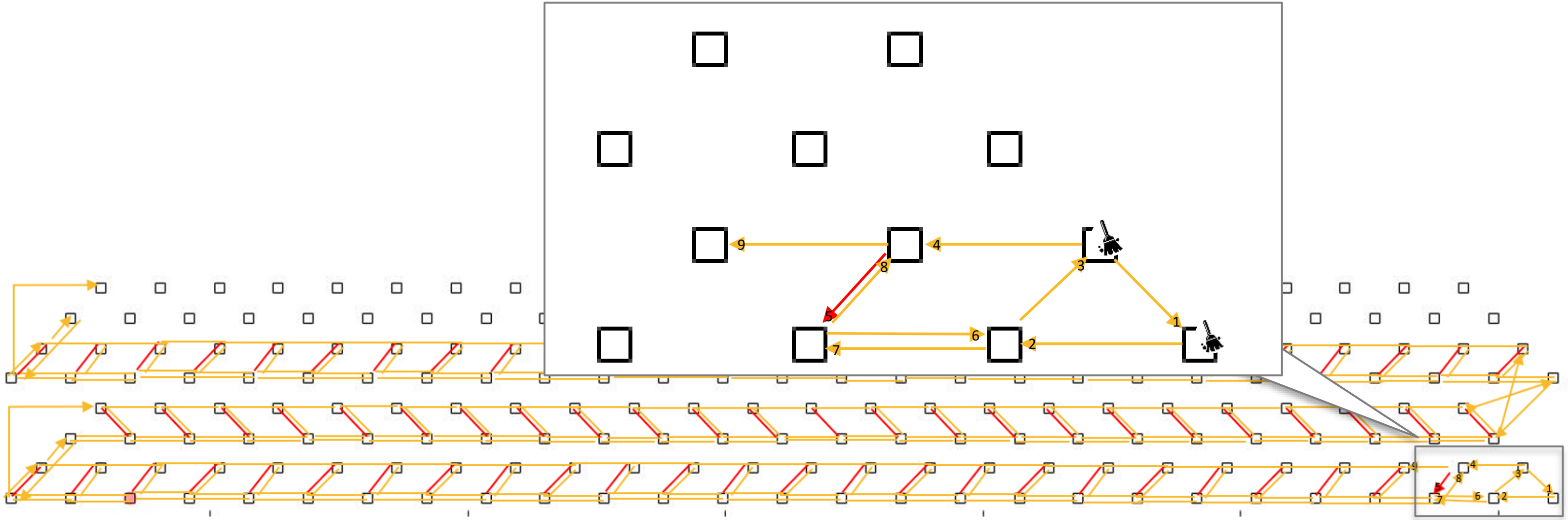


Total water to clean field [l] = 36.17
Total water required per device [l] = 36.17
Total time to clean field [hours] = 37.61
Drone waiting time (per set of mirrors) [min] = 3.13
Drone total airborne time [hours] = 9.40

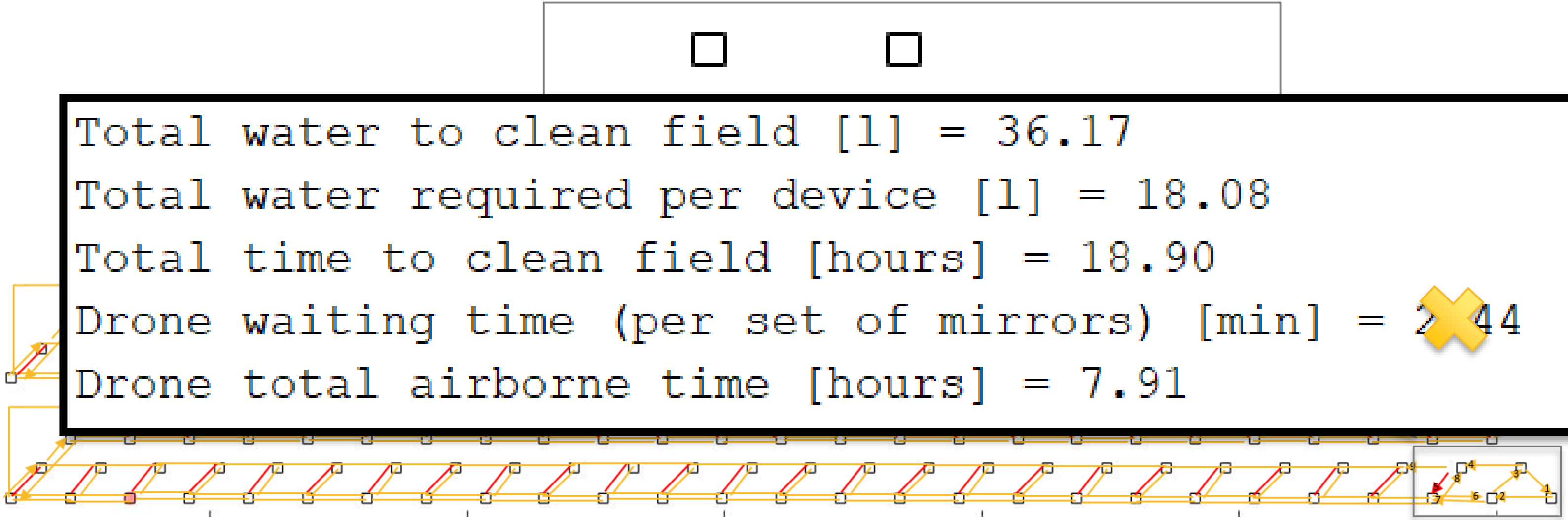
Application to Heliostat Field

Path: 2 cleaning devices



Application to Heliostat Field

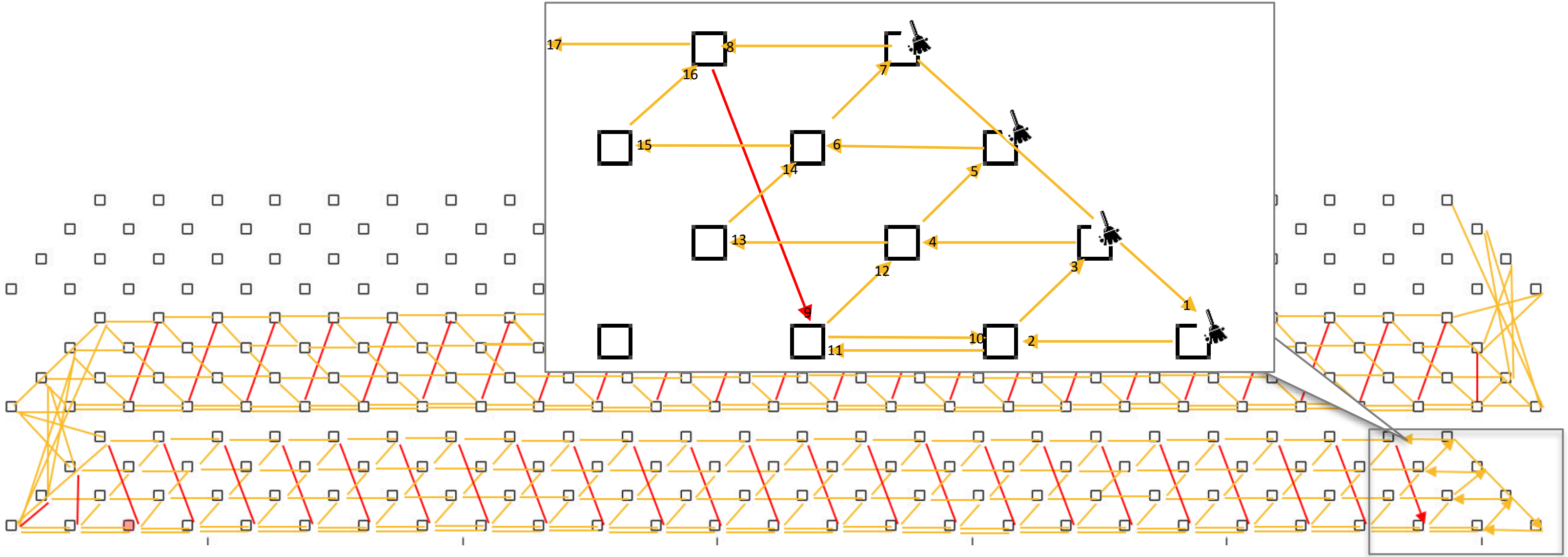
Path: 2 cleaning devices



```
Total water to clean field [l] = 36.17
Total water required per device [l] = 18.08
Total time to clean field [hours] = 18.90
Drone waiting time (per set of mirrors) [min] = 2.44
Drone total airborne time [hours] = 7.91
```

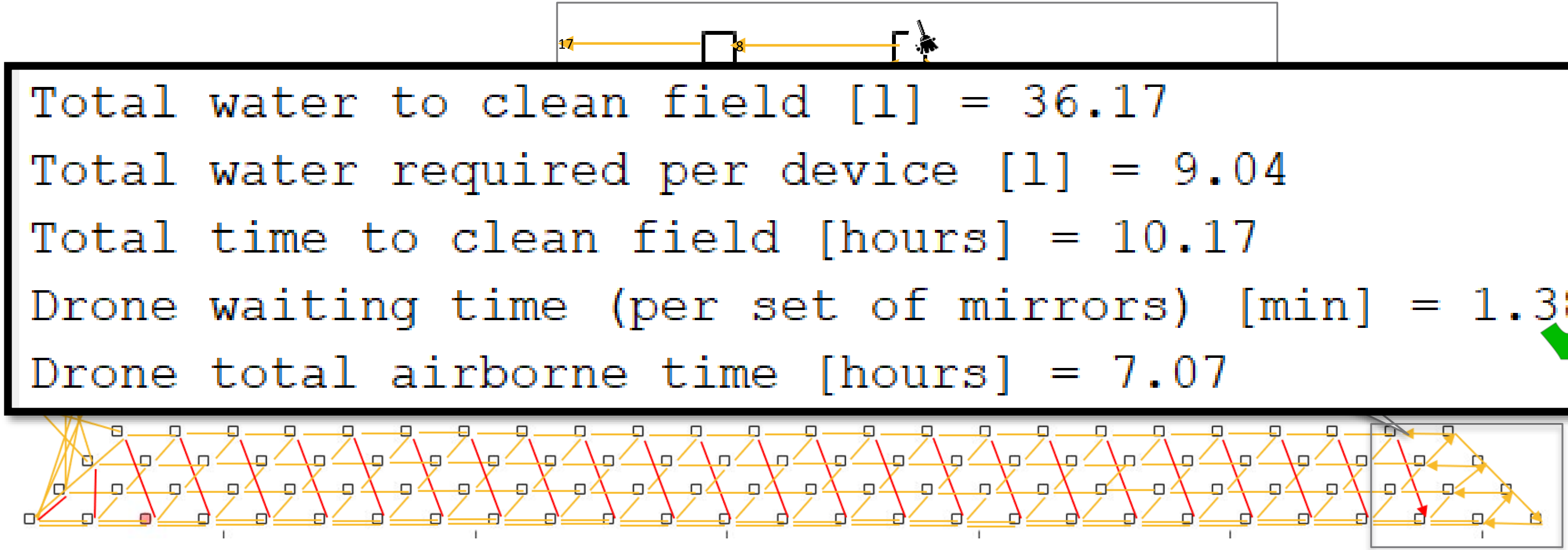
Application to Heliostat Field

Path: 4 cleaning devices



Application to Heliostat Field

Path: 4 cleaning devices



Total water to clean field [l] = 36.17

Total water required per device [l] = 9.04

Total time to clean field [hours] = 10.17

Drone waiting time (per set of mirrors) [min] = 1.38 ✓

Drone total airborne time [hours] = 7.07

Application to Heliostat Field

Decide payload and flight time according to constraints

- Main constraint:
  - Clean each mirror every **7 days**
- Total water required per device:
  - 9 liters (for the entire field)/ 7 days **= 1.3 l/ day**
- Required airborne time per day:
  - 7 hours (for the entire field)/7 days **= 1 h/day**

```
Total water to clean field [l] = 36.17
Total water required per device [l] = 9.04
Total time to clean field [hours] = 10.17
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Total water to clean field [l] = 36.17
Total water required per device [l] = 9.04
Total time to clean field [hours] = 10.17
Drone waiting time (per set of mirrors) [min] = 1.38
Drone total airborne time [hours] = 7.07
```
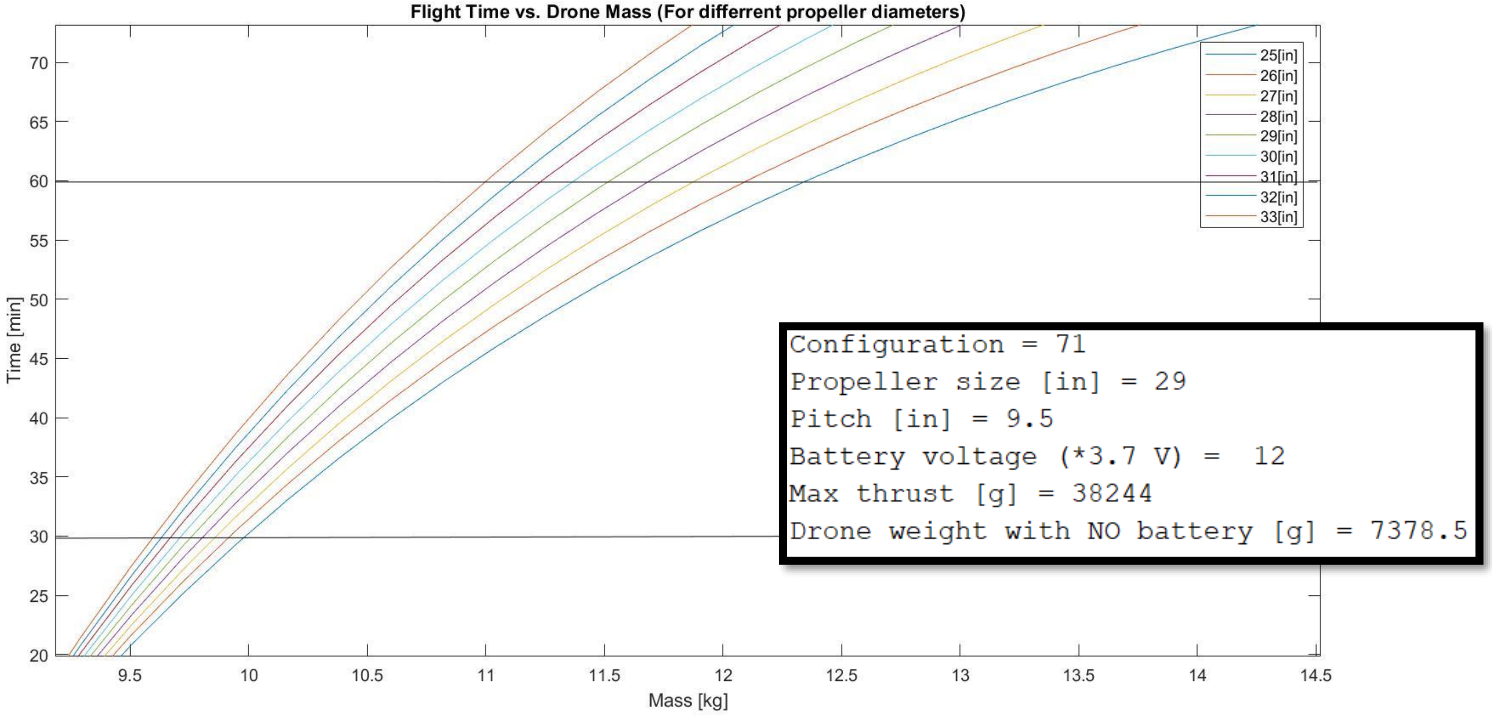

- **Payload:**
  - 2kg (cleaning robot) + 1.5 kg (water) + 0.5 kg (safety margin) = **4kg**
- **Flight time:**
  - No battery recharge = **1 h**
  - 1-time battery recharge = **30 min**

Application to Heliostat Field

Plug in Payload and Flight time into Drone Selection Model



Configuration = 71
Propeller size [in] = 29
Pitch [in] = 9.5
Battery voltage (*3.7 V) = 12
Max thrust [g] = 38244
Drone weight with NO battery [g] = 7378.5

Application to Heliostat Field

Flight time: **30 min**

Payload: **4kg**

Diameter_in	pitch_in	Batt_Energy_mAh	Batt_Weight_g	AUW_g	RPM	Power_W	Torque_Nm
25	8.1	6000	2567	9945	2281	228	0.95
26	8.4	6000	2567	9945	2114	219	0.99
27	8.7	6000	2567	9945	1964	211	1.02
28	9	5000	2348	9727	1810	197	1.04
29	9.4	5000	2348	9727	1676	190	1.08
30	9.7	5000	2348	9727	1569	183	1.12
31	10	5000	2348	9727	1472	178	1.15
32	10.3	4000	2130	9508	1368	166	1.16
33	10.7	4000	2130	9508	1279	161	1.2

Flight time: **1 h**

Payload: **4kg**

Diameter_in	pitch_in	Batt_Energy_mAh	Batt_Weight_g	AUW_g	RPM	Power_W	Torque_Nm
25	8.1	17000	4968	12346	2542	315	1.18
26	8.4	16000	4750	12128	2334	295	1.21
27	8.7	15000	4531	11910	2149	276	1.23
28	9	14000	4313	11691	1984	259	1.25
29	9.4	13000	4095	11473	1820	243	1.28
30	9.7	13000	4095	11473	1704	235	1.32
31	10	12000	3876	11255	1584	221	1.33
32	10.3	11000	3658	11037	1474	208	1.35
33	10.7	11000	3658	11037	1378	202	1.4

Application to Heliostat Field

Flight time: 30 min

Diameter_in	pitch_in	Batt_Energy_mAh	Batt_Weight_g	AUW_g	RPM	Power_W	Torque_Nm
25	8.1	6000	2567	[illegible]	2281	228	0.95
26	8.4	6000	2567	[illegible]	2114	219	0.99
27	8.7	6000	[illegible]	[illegible]	1964	211	1.02
28	9	5000	[illegible]	[illegible]	1810	197	1.04
29	9.4	5000	[illegible]	[illegible]	1676	190	1.08
30	9.7	5000	[illegible]	[illegible]	[illegible]	183	1.12
31	10	[illegible]	[illegible]	[illegible]	[illegible]	178	1.15
32	10.3	[illegible]	[illegible]	[illegible]	1368	166	1.16
33	10.7	[illegible]	[illegible]	[illegible]	1279	161	1.2

Flight time: 1 h

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Compare limitations and costs

Summary & Conclusion

- **Heliostat Cleaning:** is a key operation in CSP plants. Automation of this operation will be beneficial.
- **Drone Selection Model:** A high-level model is necessary to estimate drone's characteristics for a specific application.
- **Application to Heliostat Field:** To estimate the payload and flight-time of the drone, a path must be designed, while considering the plant's operation constraints.


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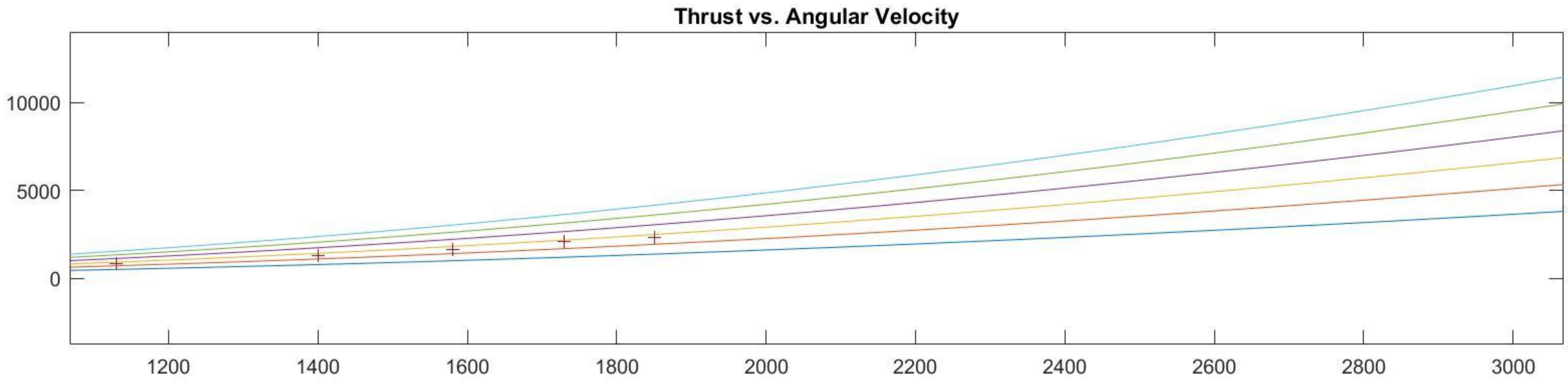
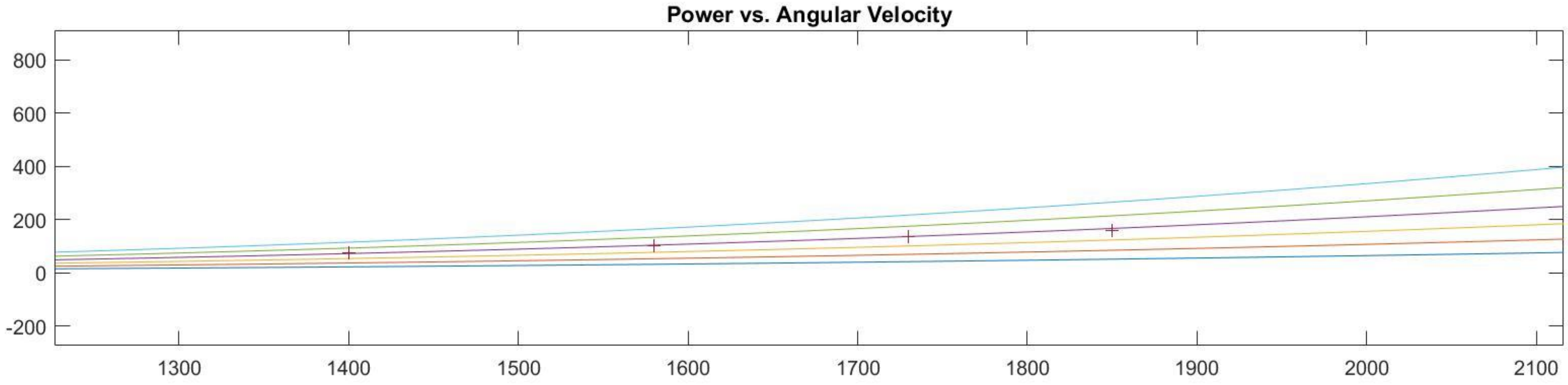
Thank You

Backup Slide





Backup Slide

Item No.	Voltage (V)	Propeller	Throttle	Current (A)	Input power (W)	RPM	Torque (N*m)	Thrust (g)	Efficiency (g/W)
U10II KV100	12S (48V)	T-motor G29*9.5CF	40%	3.9	189.5	1583	0.77	2424	12.79
			42%	4.4	213.8	1654	0.85	2611	12.21
			44%	4.8	234.7	1724	0.91	2859	12.17
			46%	5.3	257.8	1791	0.98	3026	11.73
			48%	6.2	301.4	1909	1.09	3480	11.54
			50%	6.6	319.1	1962	1.14	3556	11.14
			52%	7.2	349.6	2044	1.22	3851	11.01
			54%	7.8	378.5	2102	1.29	4090	10.80
			56%	8.3	405.0	2162	1.35	4270	10.54
			58%	8.9	430.5	2227	1.4	4439	10.31
			60%	9.6	467.8	2293	1.49	4701	10.04

Diameter_in	pitch_in	Batt_Energy_mAh	Batt_Weight_g	AUW_g	RPM	Power_W	Torque_Nm
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Application to Heliostat Field

Cost Comparison

$340*4

$340*2

$100

$100

30 min

$200

1 h

$400