Silicon Valley Early Adopter CONOPs and Market Study

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2015 Transformative Vertical Flight Workshop

What If community friendly and cost effective civil VTOL concepts can be enabled by new electric propulsion and autonomy technologies to offer high speed urban transportation?

This study is still at an early stage, with interim results being presented to get feedback on assumptions and approaches

Objective: Develop strategies to achieve a highly distributed mix of public and private Helipad infrastructure in a specific compelling early adopter market region.

Output: Understand the level of Helipad distribution that can be reasonably achieved, the CONOPs assumptions, and the resulting vehicle requirements.

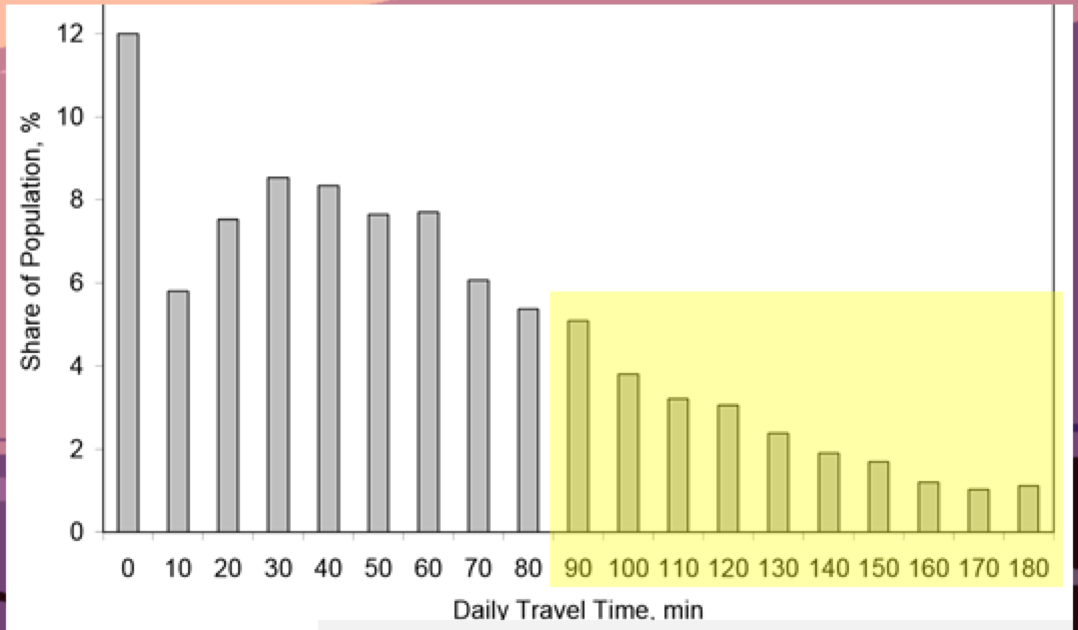
- Why is the Silicon Valley a great Early Adopter Market for civil VTOL?
    - Hyper/Mega/Super Commuter Studies
- Hyper Commuter City-Pairs
- The Problem
    - Auto Travel Times Due to Ground Obstructions, Limited Routes and Congestion
- Past Solutions
    - Metro, Public Transit, High-Speed Rail, etc.
- Infrastructure Development
    - Public and Private, Urban and Metropolitan
- Enabled Travel Times
- CONOPs Assumptions
- Resulting Vehicle Requirements

Metro Areas with Highest Mean Distance	Percent Mega Commutes
San Francisco-Oakland-Fremont, CA	2.06
San Jose-Sunnyvale-Santa Clara, CA	1.90
Salinas, CA	1.23
Gulfport-Biloxi, MS	0.94
Hinesville-Fort Stewart, GA	0.93
Lawton, OK	0.82
Fayetteville, NC	0.73
Brunswick, GA	0.64
Anchorage, AK	0.25
Honolulu, HI	

U.S. Census Mega Commuter Study

Top 3 Metro Areas

All in the Silicon Valley



Long-Term Trends in Global Passenger Mobility, Andreas Schaefer

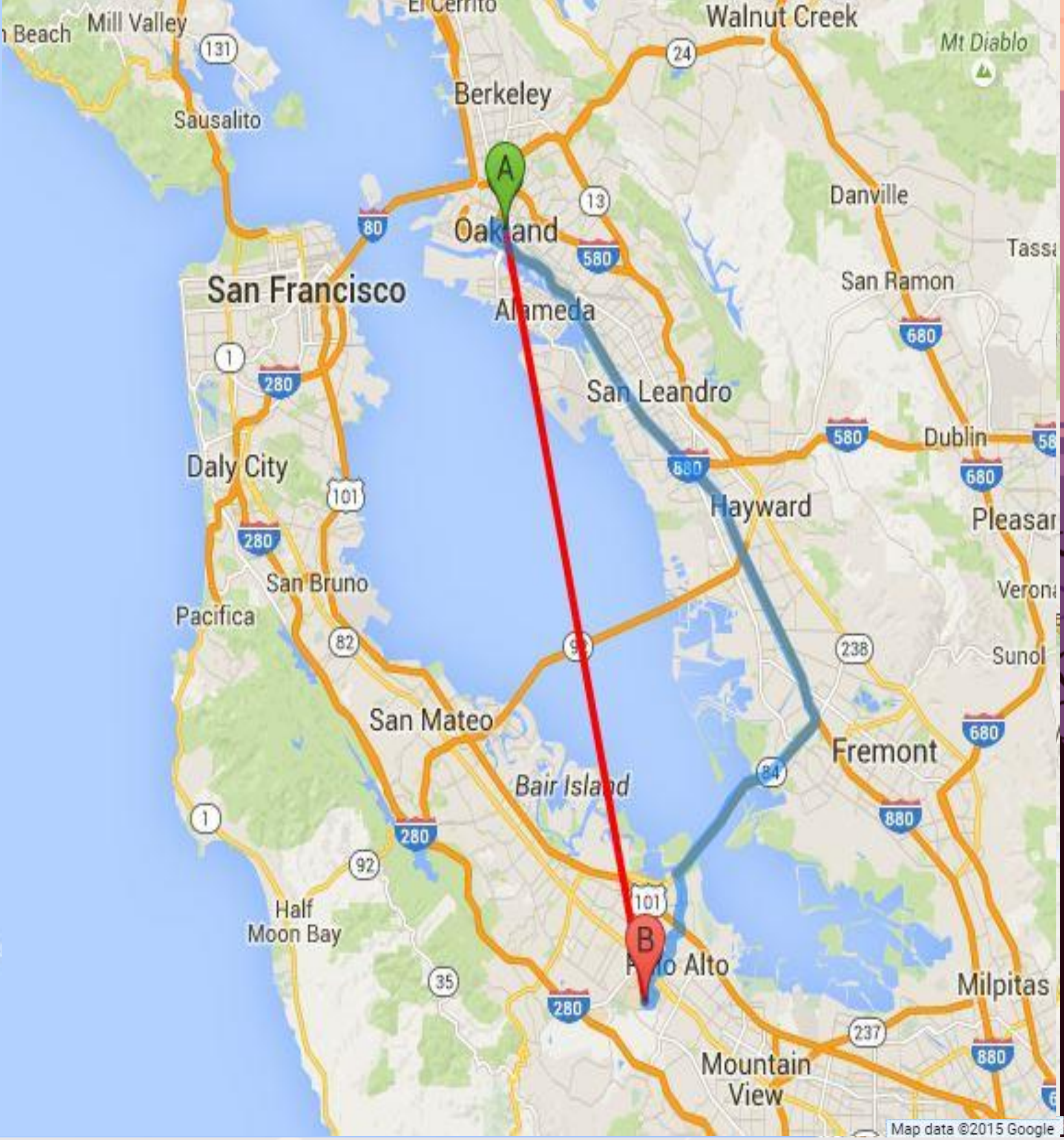
>25% have Daily Travel Times of >90 min.

Travel Statistics: Silicon Valley #1 commuter travel distance and time

Demographics: High income, high housing costs, high tech adoption rates

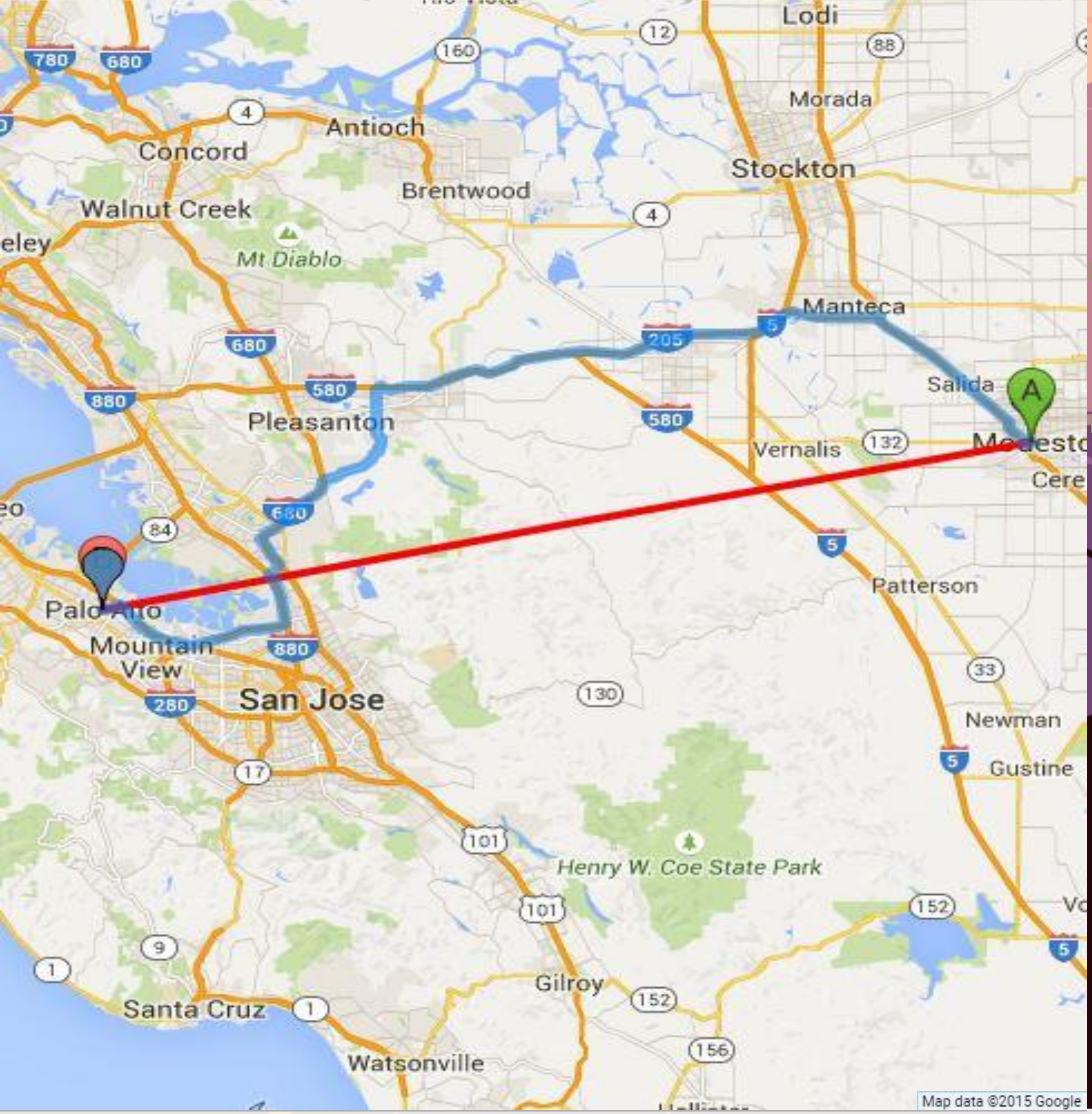
Capital Environment: Ability to attract capital for local/regional perceived needs

Location: Significant ground terrain obstructions, Near perfect weather



		Ground Travel Time (min)		Driving Distance (miles)	Average Speed (mph)	
City 1	City 2	Non-Peak	Peak		Non-Peak	Peak
H.M. Bay	San Fran.	40	75	30	45	24
Santa Cruz	Mt. View	45	110	36	48	20
Morgan Hill	Palo Alto	45	120	38	51	19
San Fran.	San Jose	55	90	48	53	32
Fremont	Cupertino	30	75	25	50	20
Pleasanton	Sunnyvale	40	100	28	43	17
Walnut Crk.	Daly City	40	110	32	49	18
Oakland	Stanford	55	120	36	39	18
San Rafael	Fremont	55	110	49	53	27
Mill Valley	RW City	60	120	40	40	20
	Average:	**47**	**103**	**36**	**47**	**21**

Average Speed: **47** (Non-Peak) | **21** (Peak) mph



City 1	City 2	Ground Travel Time (min) Non-Peak	Ground Travel Time (min) Peak	Driving Distance (Miles)	Average Speed (mph) Non-Peak	Average Speed (mph) Peak
Monterey	San Fran.	120	220	119	60	33
Los Banos	Mt. View	90	180	91	61	30
Stockton	San Jose	90	150	76	50	30
Modesto	Palo Alto	90	210	89	59	25
Sacramento	San Fran.	90	200	88	59	26
Napa	Mt. View	90	200	86	57	26
Santa Rosa	Cupertino	110	200	107	58	32
Merced	Mt. View	130	200	127	59	38
Merced	San Mateo	130	200	128	59	38
Los Banos	Fremont	90	150	95	63	38
Sacramento	Oakland	80	160	82	61	31
S.Lake Tahoe	Palo Alto	220	340	219	60	39
Redding	San Fran.	190	310	217	68	42
	Average:	**117**	**209**	**117**	**60**	**34**

Average Speed: **60** (Non-Peak) | **34** (Peak) mph

The Problem | Travel Times for Suburban City-Pairs

Urban

City 1	City 2	Air (miles)	Road (mi)
Half Moon Bay	San Francisco	22	30
Santa Cruz	Mountain View	29	36
Morgan Hill	Palo Alto	34	38
San Francisco	San Jose	42	48
Fremont	Cupertino	16	25
Pleasonton	Sunnyvale	22	28
Walnut Creek	Daly City	27	32
Oakland	Stanford	27	36
San Rafael	Fremont	42	49
Mill Valley	Redwood City	34	40
Average		**29**	**36**

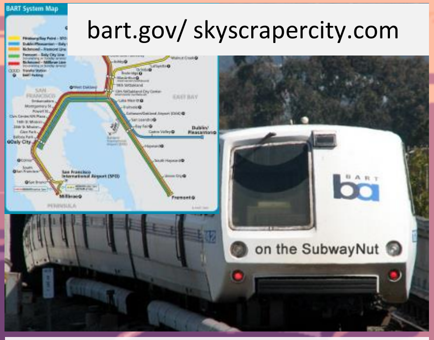
Ground Travel **1.2** x Longer Distance

Suburban

City 1	City 2	Air (miles)	Road (mi)
Monterey	San Francisco	86	119
Los Banos	Mountain View	72	91
Stockton	San Jose	54	76
Modesto	Palo Alto	64	89
Sacramento	San Francisco	75	88
Napa	Mountain View	64	86
Santa Rosa	Cupertino	86	107
Merced	Mountain View	88	127
Merced	San Mateo	103	128
Los Banos	Fremont	71	95
Sacramento	Oakland	68	82
S. Lake Tahoe	Palo Alto	157	219
Redding	San Francisco	194	217
Average:		**91**	**117**

Ground Travel **1.3** x Longer Distance

Buses



Subway

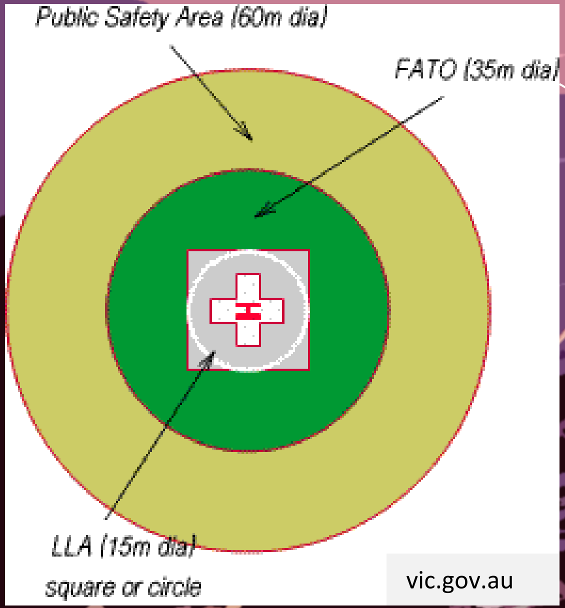
High-Speed Rail

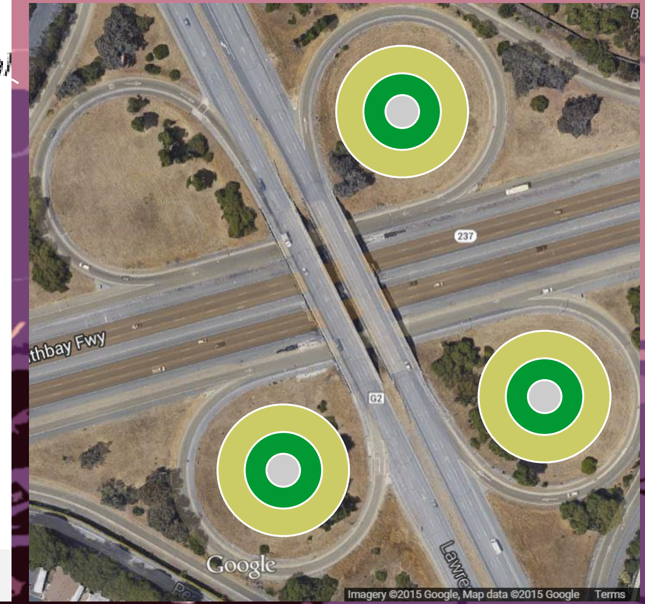
Runway Required PAVs

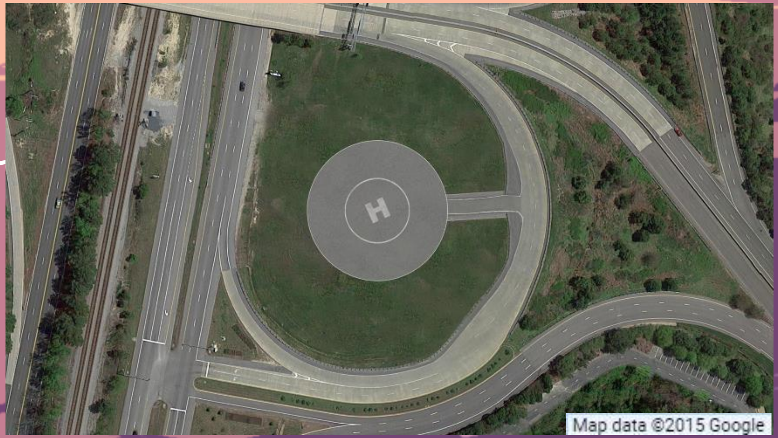
Distributed Solutions: Cars, Buses attempt to aggregate trips along established routes, penalizing travel time.

Centralized Solutions: GA airports that are sparse, BART/Rail limited to high density routes (at great expense) none of which are effective at meeting distributed travel needs.

Optimum Solution: High travel speeds, highly distributed operations, direct routing, no trip aggregation.

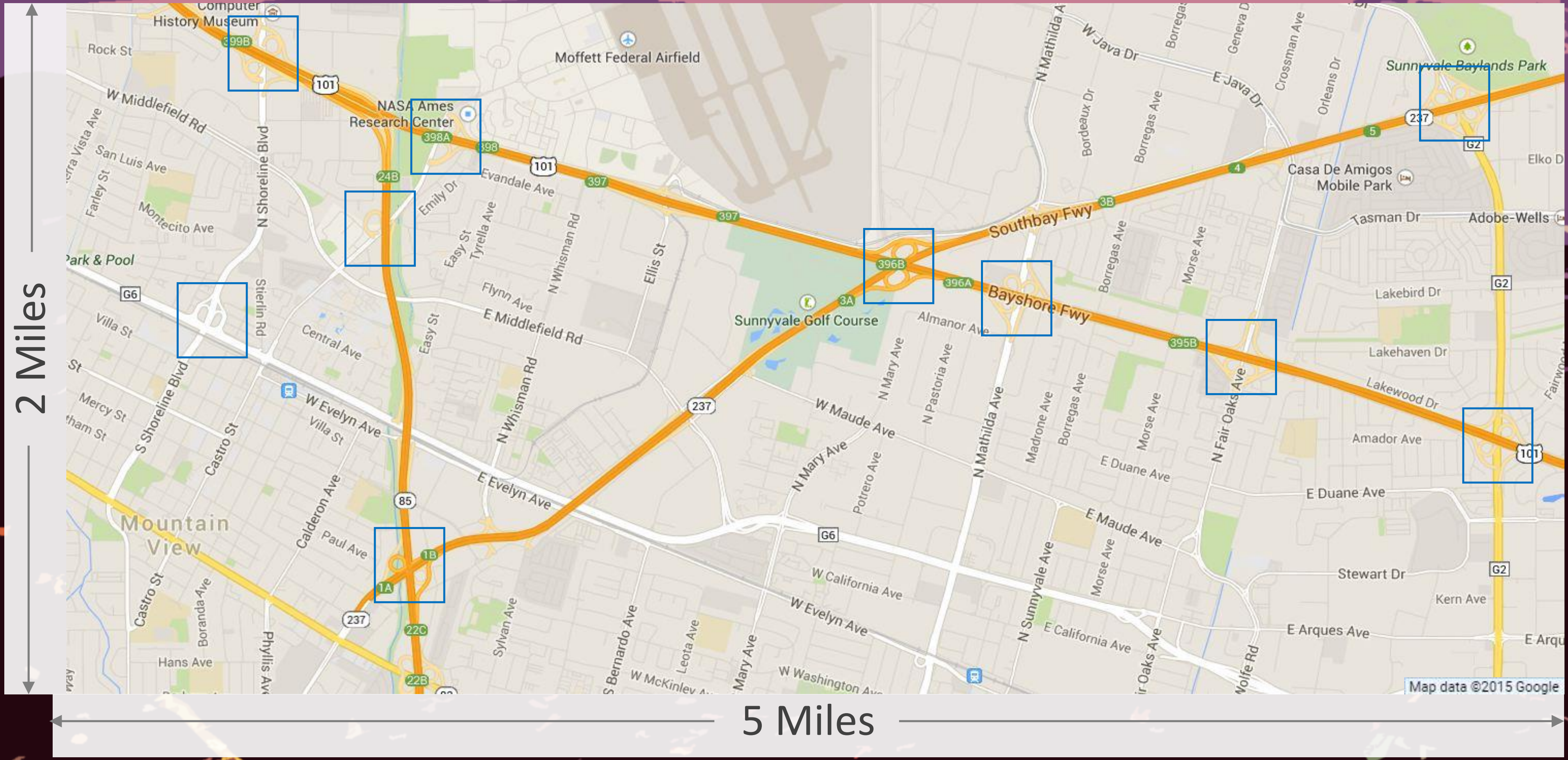






- Available DOT land resource provides approach/departure paths without overflight of private property at <500 ft.
- Existing high noise area that the community accepts with established setbacks
- Distribution that couples to existing ground roads for minimum travel time

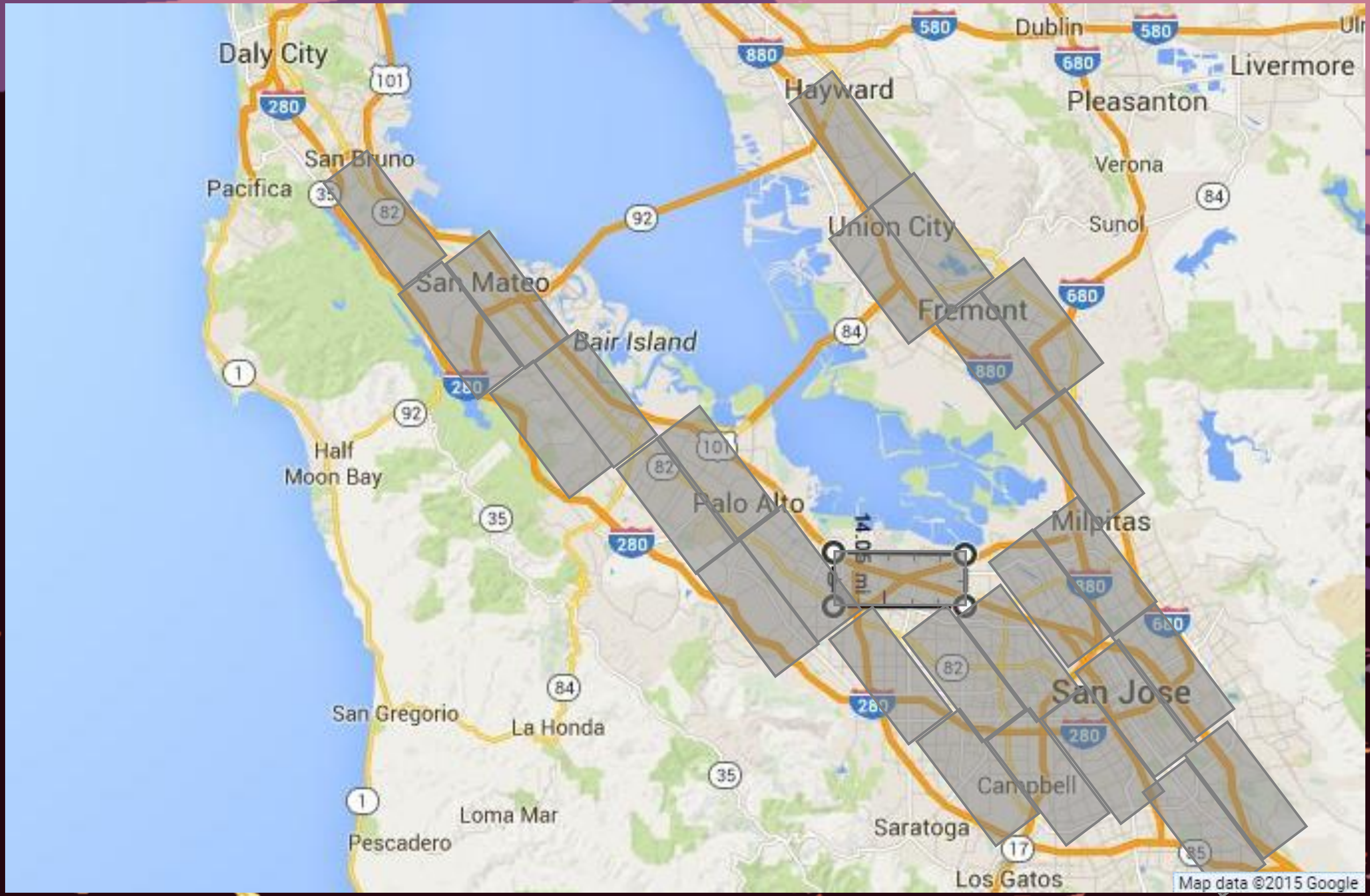
10 Sq. Miles | 10 Intersections | 19 Potential Helipads



Selection Criteria:

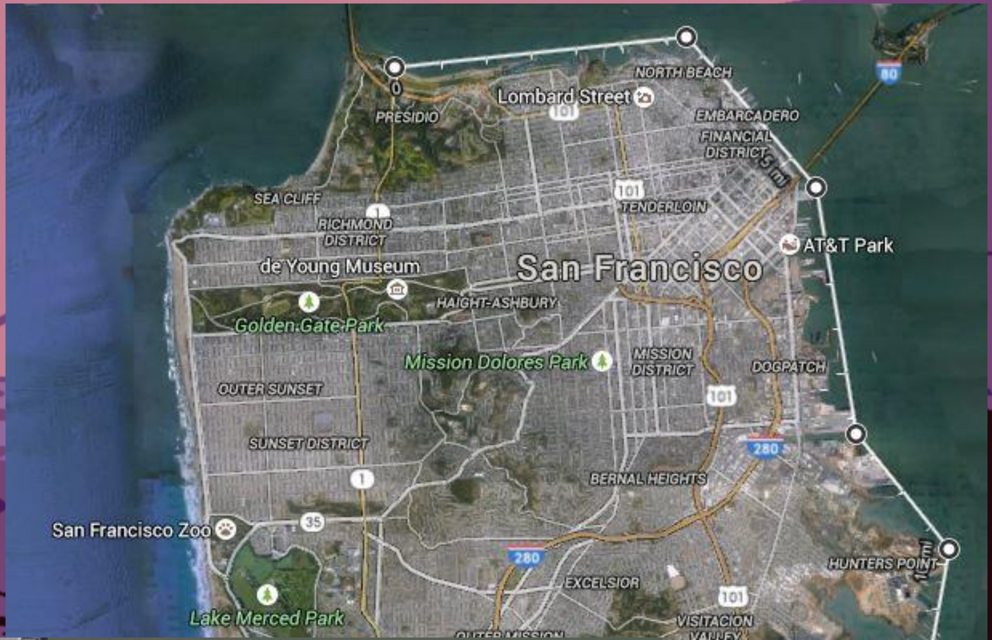
- > 200 ft. diameter cloverleaf
- No obstructions

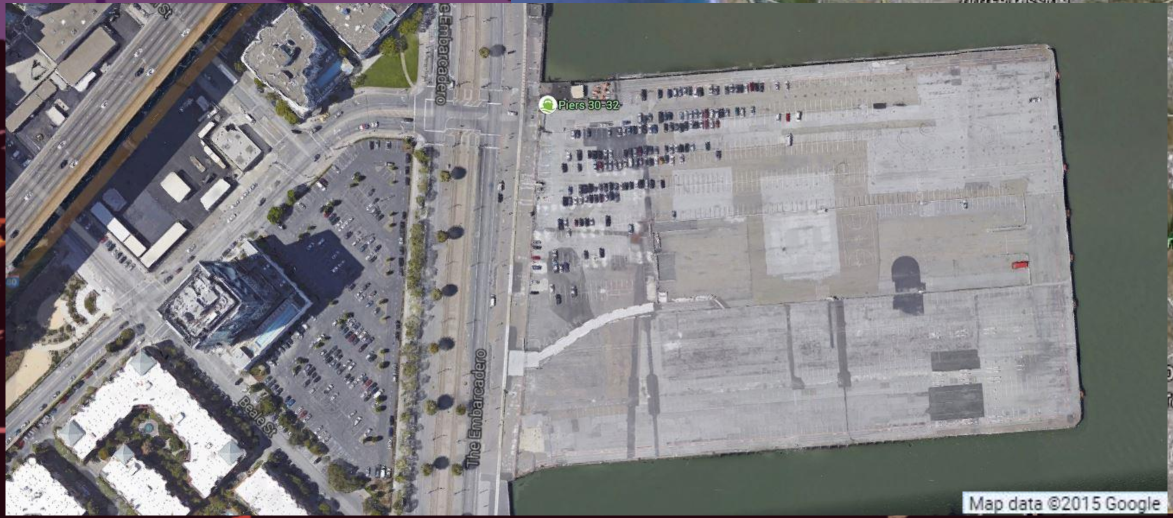
280 Sq. Miles | 105 Intersections | 200 Potential Helipads



- Hand-picked intersections with at least 1 cloverleaf
- 1.9 helipads/ intersection determined in previous slide
- Therefore, ~200 potential helipads
- Average of 200/280 = 0.71 helipads per sq. mile
- Establishing this average ground separation distance determines ground travel distance for door to door travel speed achieved

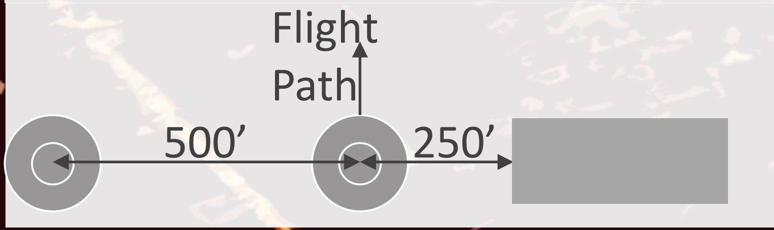
18 Coastal Miles | 50 Potential Helipads

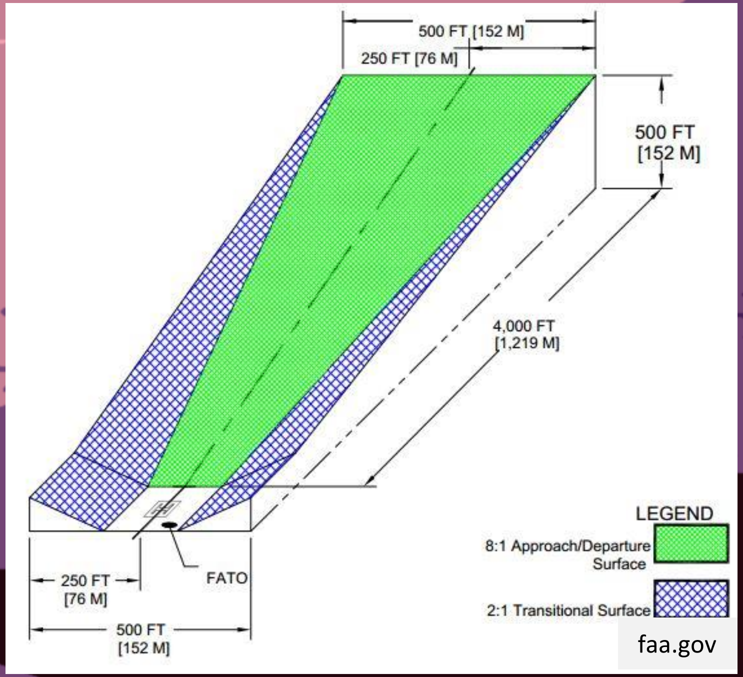




Selection Criteria:

- Direct Roadway Access
- 500′ distance between two helipads perpendicular to flight path
- 250′ distance from center of helipad to other obstruction perpendicular to flight path

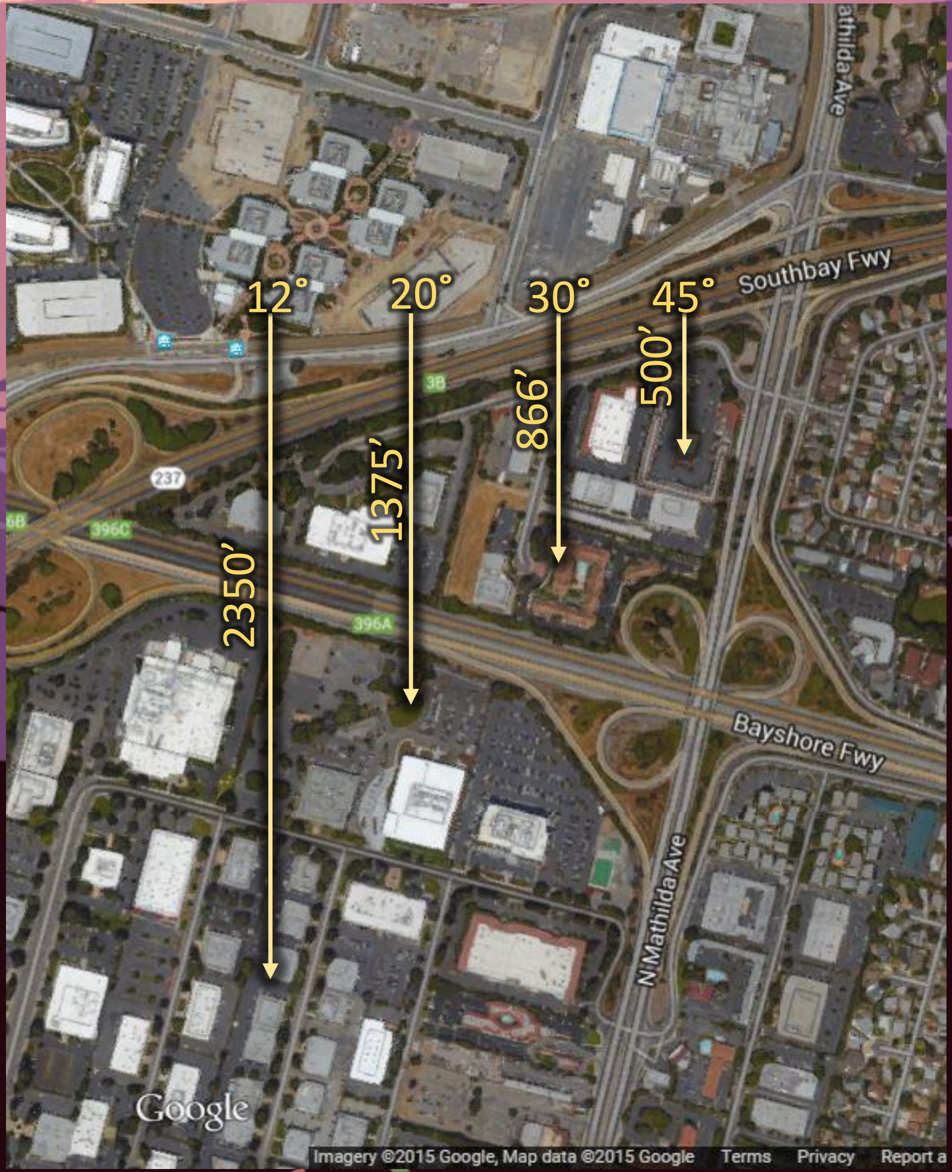




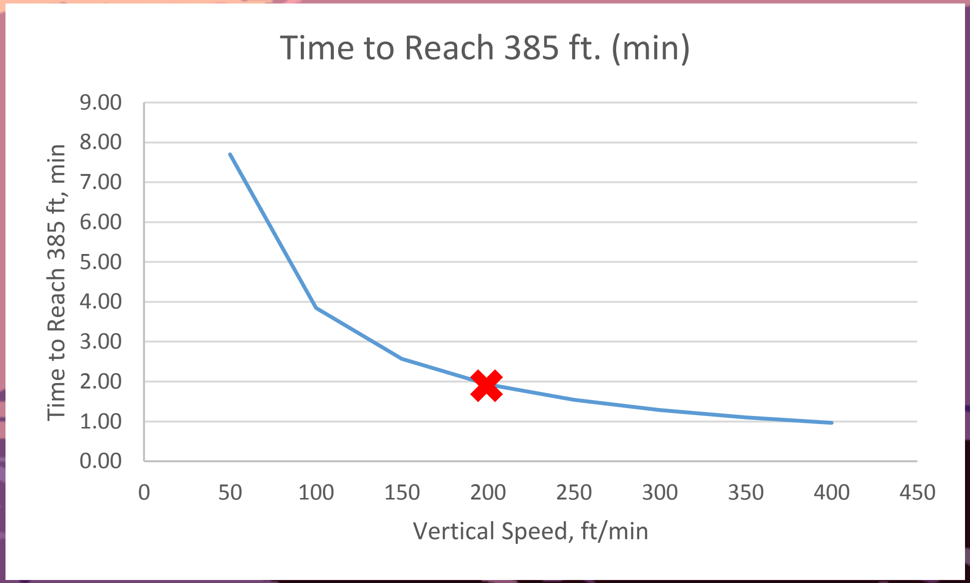
Additional Requirements:

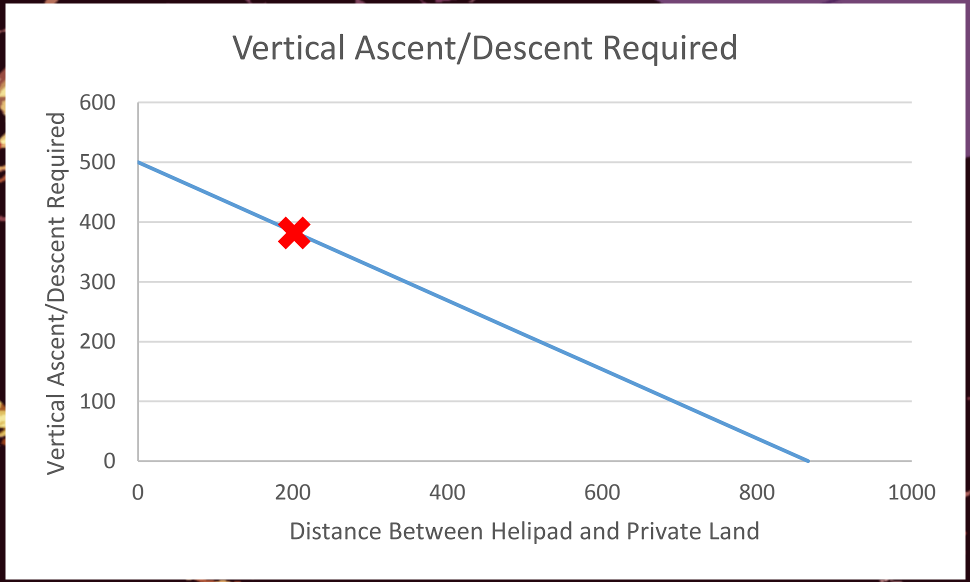
- Min: 45 deg. crosswind
- 500 ft. private ground clearance

- At a given glide slope, how much horizontal distance is needed to reach a minimum private land clearance of 500’?
  - CTOL | 3˚ | 9550’ (not shown)
  - STOL | 12˚ | 2350’
  - 20˚ | 1375’
  - **30˚ | 866’**
  - 45˚ | 500’
- 30˚ was chosen because current DEP systems have shown the ability to achieve a high-lift L/D as low as 2 at approach speeds of ~20 knots.



Glide Slope Assumption





- 200 ft. minimum distance from Landing and Lift Off Area (LLA) of helipad to private land
- 385 ft. vertical ascent/descent required to meet minimum 500 ft. flyover of private land
- 200 ft./min. -> 1.9 min. block time penalty for each ascent/descent

Minimum Distance to Private Land


30˚
500 ft.
400 ft.
80 ft.
530 ft.
140 ft.
20 ft.
8:1 Approach/Departure Surface
2:1 Transitional Surface
apple.com

Metropolitan

- 50 helipads
- 47 square miles
- 0.94 sq. mi./helipad
- Maximum commute with even distribution: 0.66 mi.
- Peak Travel Speed:
  - 21 MPH -> **1.9 min.**

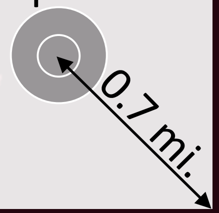
Urban

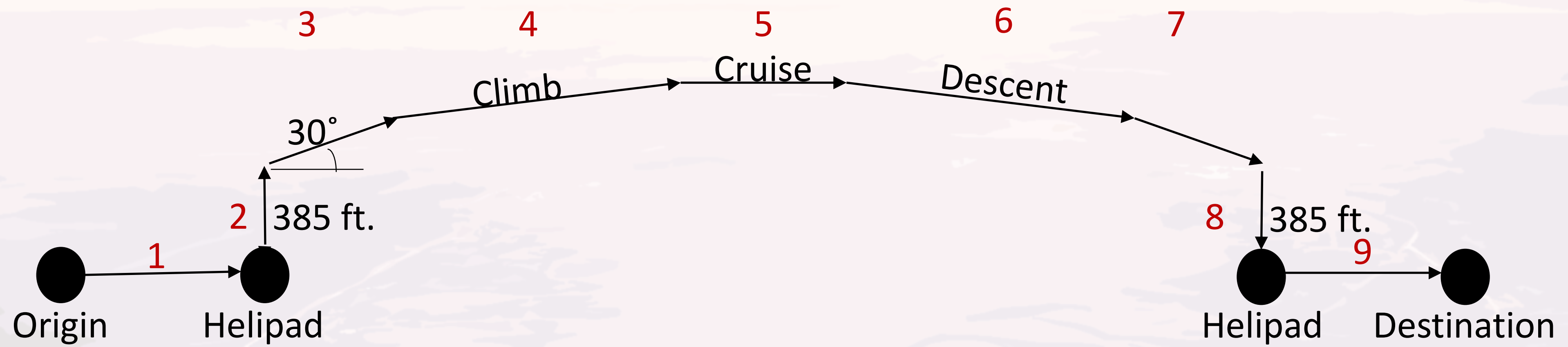
- 200 helipads
- 280 square miles
- 1.4 sq. mi./helipad
- Maximum commute with even distribution: 0.99 mi.
- Peak Travel Speed:
  - 21 MPH -> **2.8 min.**

Suburban

- Assume similar distribution to Urban
- Cheaper land acquisition costs
- Easier to satisfy setback requirements
- Faster Peak Travel Speeds:
  - 34 MPH -> **2.8 min.**

1 sq. mile per
1 helipad

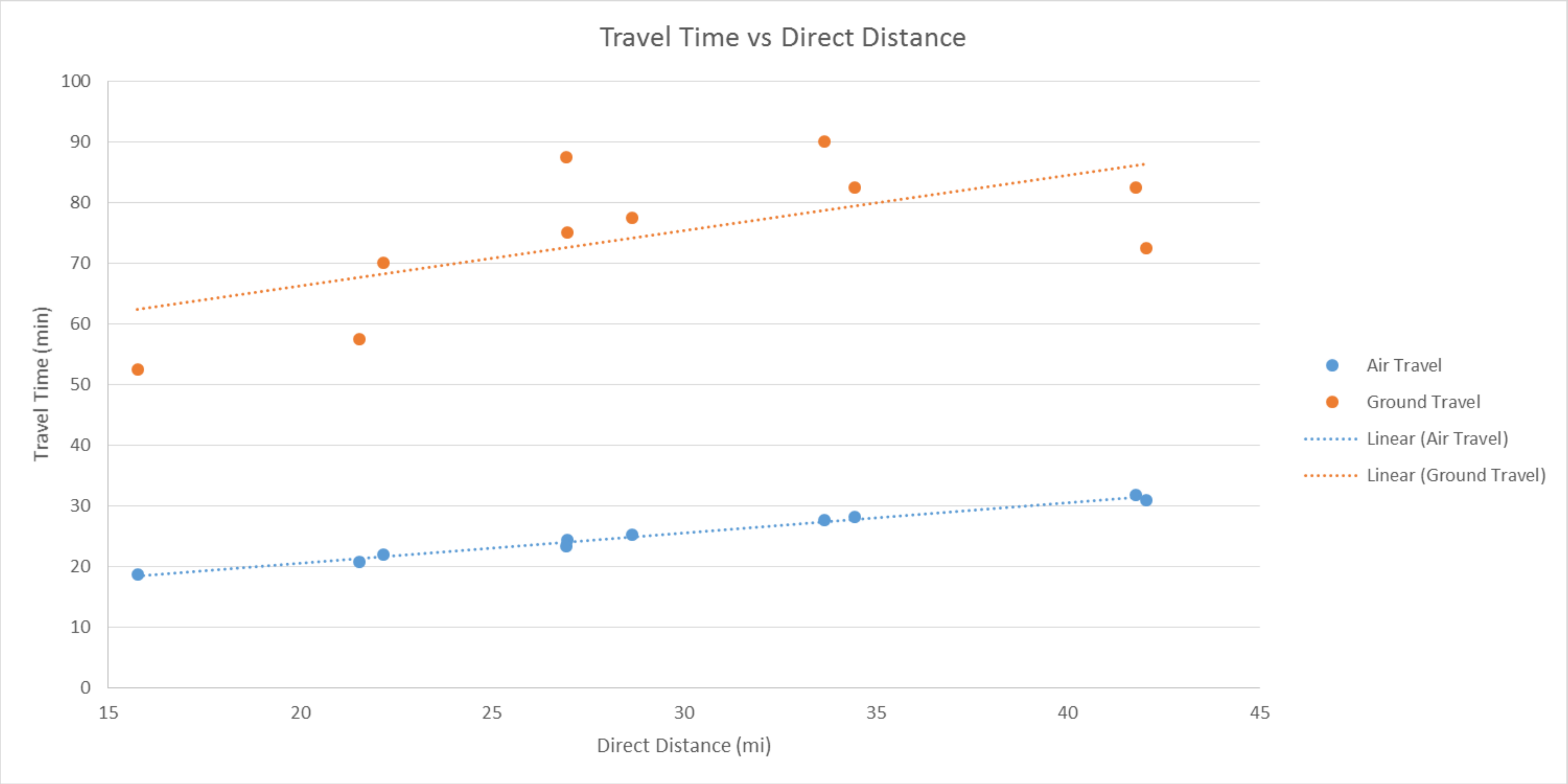




	Alt (U)	Alt (S)	Time (M)	Time (U)	Time (S)	Speed	X Dist (M, U)	X Dist (S)	Angle
1	0	0	1.9	2.8	2.8				0˚
2	385	385	1.9	1.9	1.9	200 ft/min	0	0	90˚
3	500	500	0.115	0.115	0.115	1000 ft/min	0.06	0.06	30˚
4	2,500	5,500	2	2	5	1000 ft/min	2.7	6.7	8˚
5	2,500	5,500	11.75	11.75	38.75	120mph	23.5	77.5	0˚
6	500	500	2	2	5	1000 ft/min	2.7	6.7	8˚
7	385	385	0.115	0.115	0.115	1000 ft/min	0.06	0.06	30˚
8	0	0	1.9	1.9	1.9	200 ft/min	0	0	90˚
9	0	0	1.9	2.8	2.8				0˚

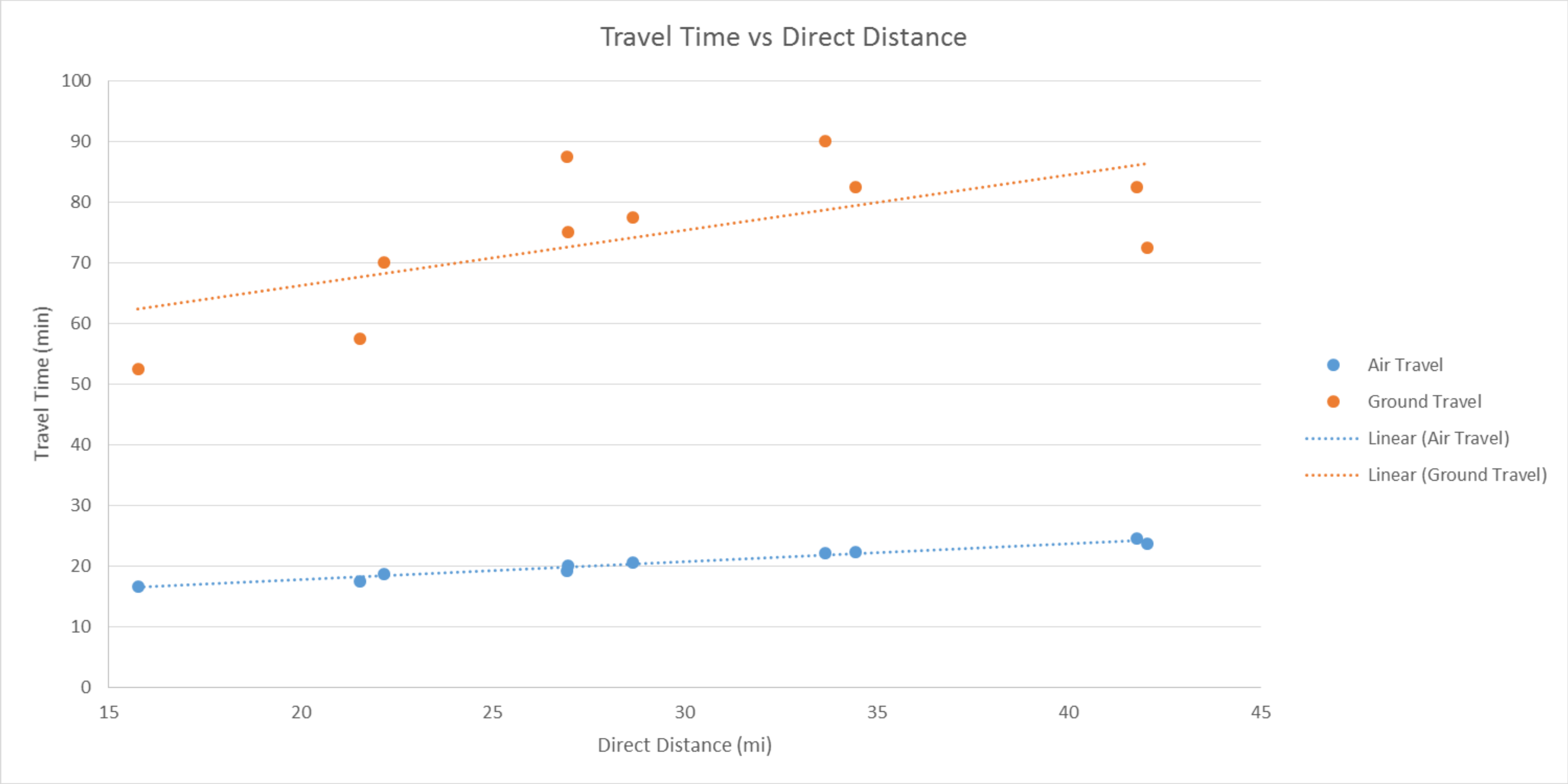
Metro->Urban | 24.5 min Urban->Urban | 25.4 min Metro->Sub | 57.4 min Urban->Sub | 58.38 min

Average Mission Block Time Buildup



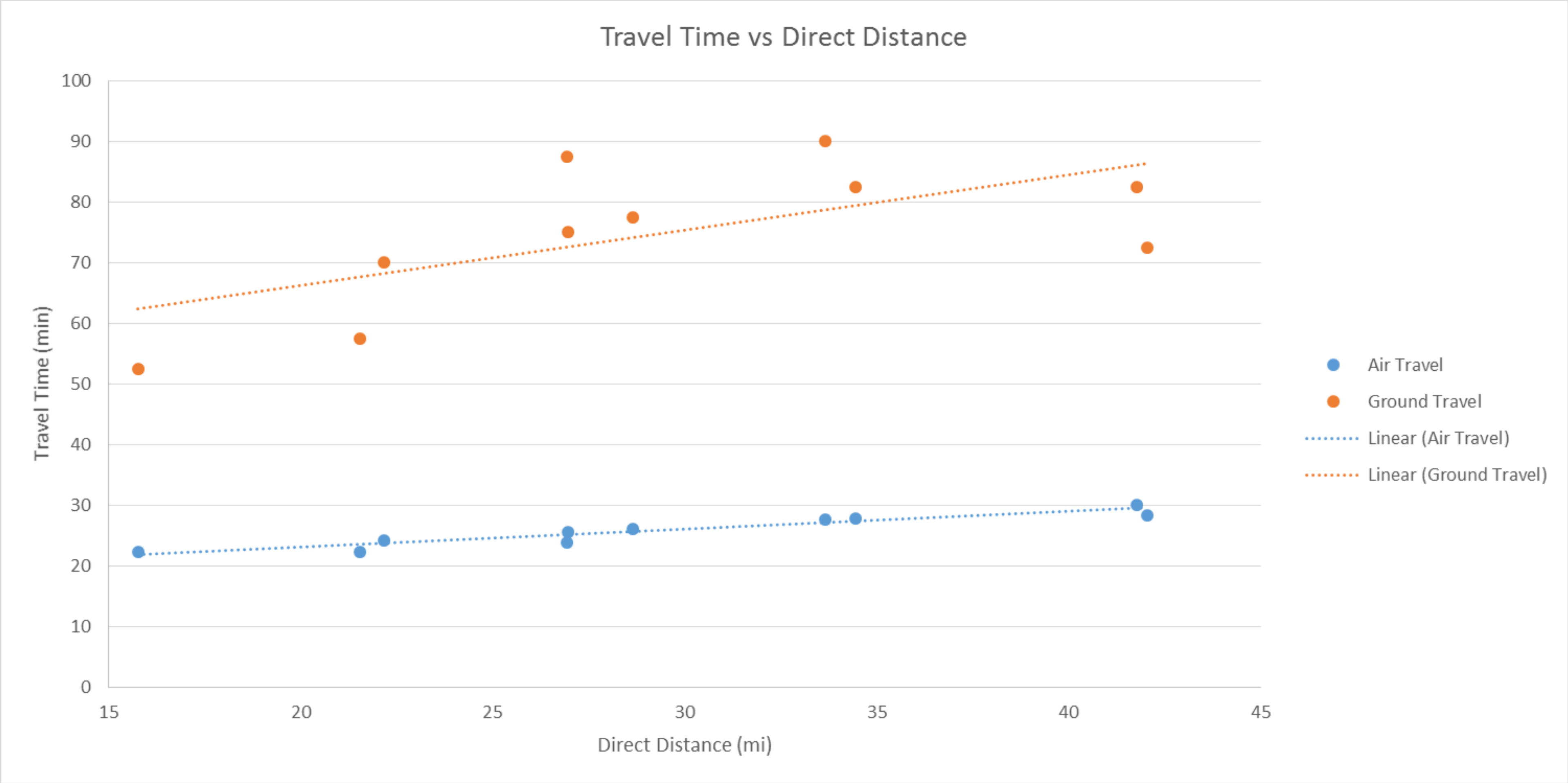
- Cruise speed:
  120 mph
- Average ground speed:
  34 mph
- Includes all block time penalties

3.0X Improvement in Travel Time



- Cruise speed:
  200 mph
- Average ground speed:
  34 mph
- Includes all block time penalties

3.6X Improvement in Travel Time

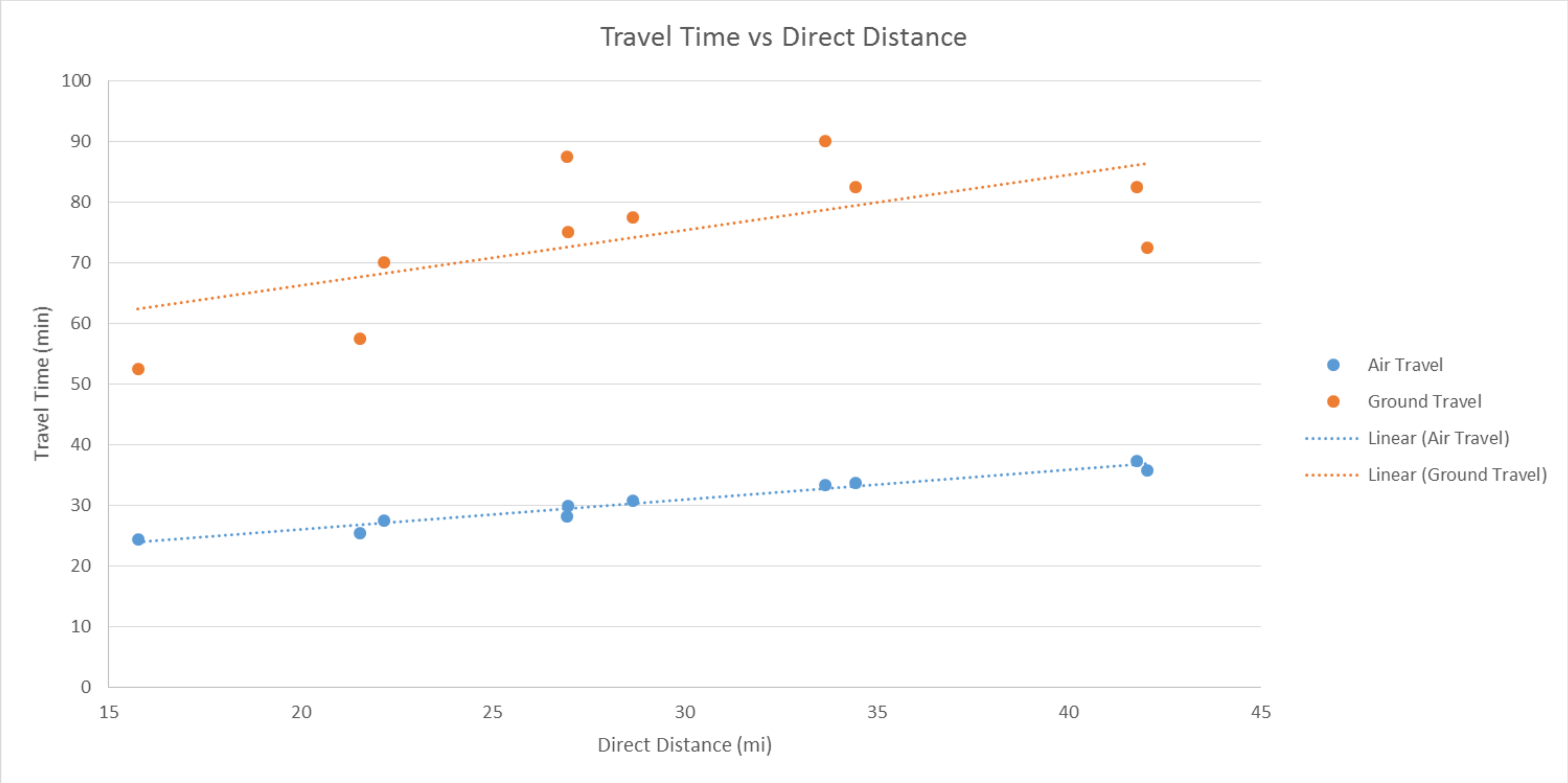


- Cruise speed:

  200 mph
- Average ground speed:

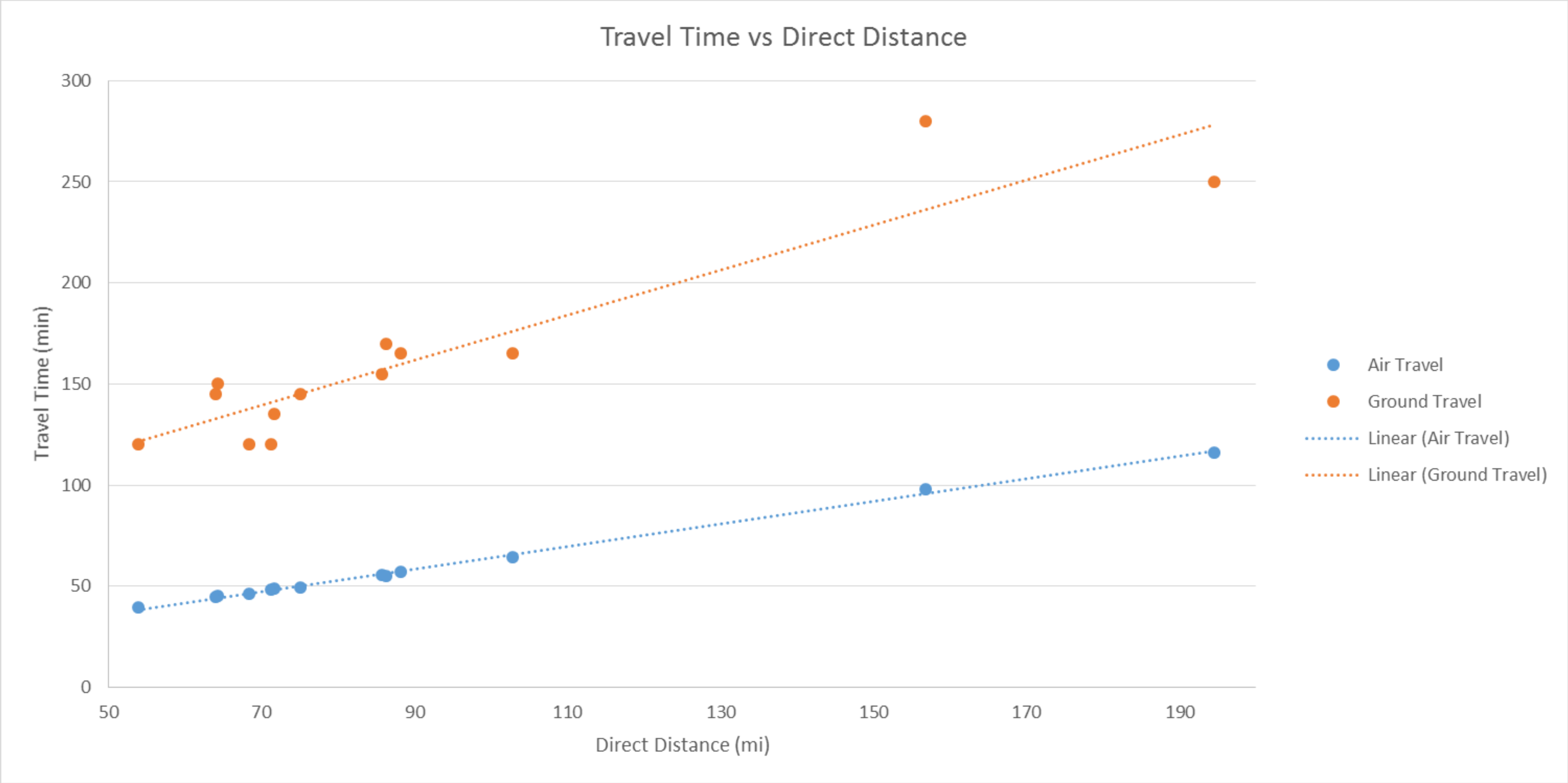
  34 mph
- Includes all block time penalties

2.9X Improvement in Travel Time



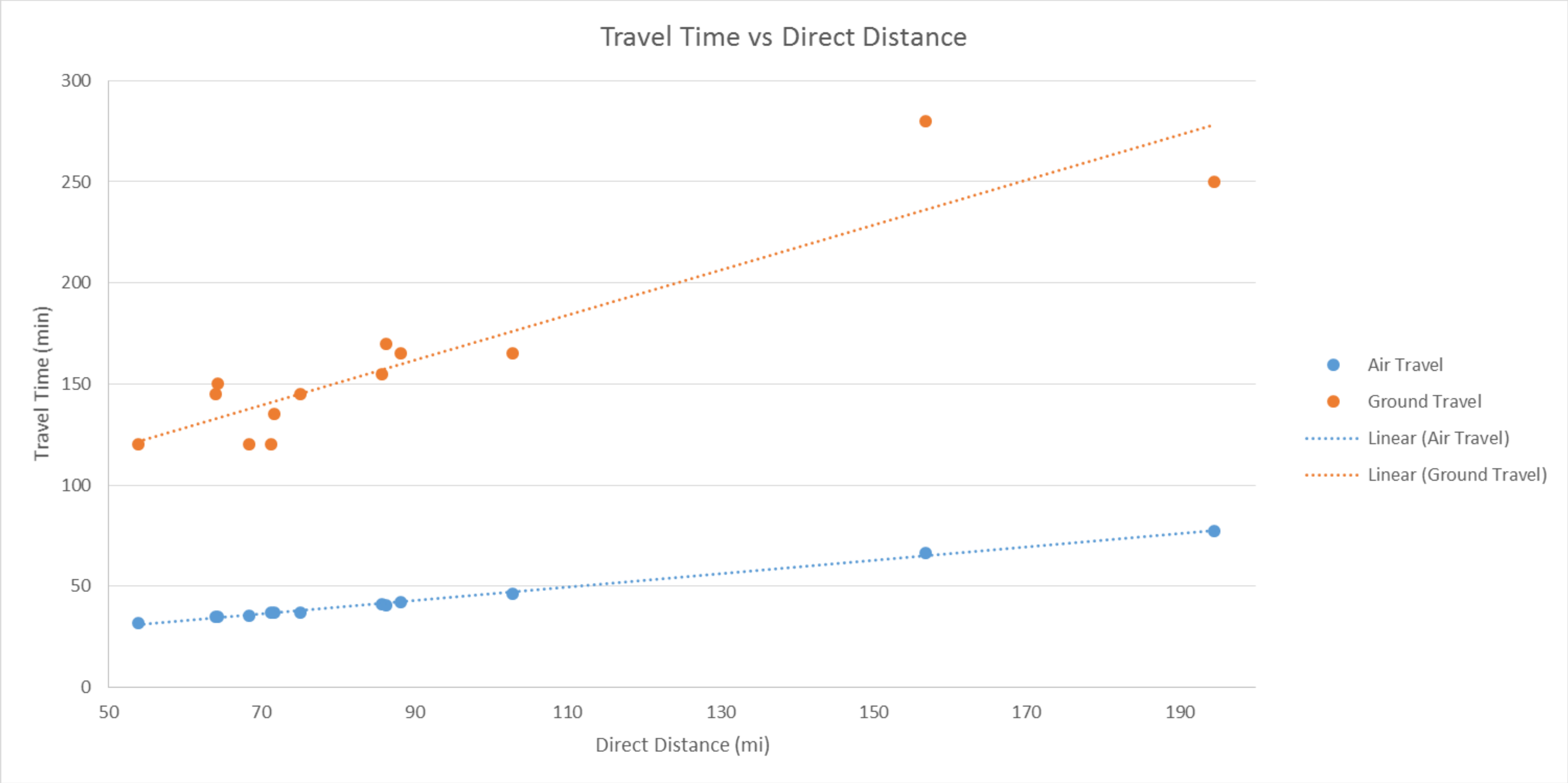
- Cruise speed:
  120 mph
- Average ground speed:
  34 mph
- Includes all block time penalties

2.4X Improvement in Travel Time



- Cruise speed:
  120 mph
- Average ground speed:
  47 mph
- Includes all block time penalties

2.6X Improvement in Travel Time



- Cruise speed:
  200 mph
- Average ground speed:
  47 mph
- Includes all block time penalties

3.7X Improvement in Travel Time

Ground	Air
Pathway-based Transportation System	Nodal-based Transportation System
Pathway-dependence creates a high level of uncertainty	Path-independent
One accident disrupts the only pathway	Multiple options to travel between nodes

- Average load factors for AirTaxi operations vary between 1.3 and 1.7 pax/trip
- Greater than 70% of all auto trips <100 miles have a single occupant
- High proximity VTOL operation feasibility likely depends on achieving the lowest possible acoustic signature
- Vehicle capacity size is assumed to be 2 people for these reasons

- <100 miles over 70% | 1.3
- >100 miles at 60% | 1.6

Travel party type and size:		
One adult, no children under 18.	386,479	58.9
Two or more adults, no children under 18 .	155,148	23.6
One adult, 1 or more children under 18 . . .	29,436	4.5
Two or more adults, 1 or more children under 18.	66,086	10.1
No adult, 1 or more children under 18	19,313	2.9
Mean travel party size (household members)	1.6	NA

>100 mile trips American Travel Survey, DOT, 1995

- **Auto:** 1.5 lbs-aircraft/lb-payload
- **CTOL:** 3 lbs-aircraft/lb-payload
- **VTOL:** 5-6 lbs-aircraft/lb-payload

Vehicle Growth Factor

- Attempted to use the 50’ field for acceleration to reduce T/W sizing, but in the end the CONOPs show that a vertical descent/ascent trajectory to meet the 500’ clearance is required.
  - Attempting to use the peak rating to reduce the T/W required and currently performing trajectory analysis to determine whether this is possible
  - A clear outcome is that these vehicles don’t require sustained hover capability, but do require a vertical descent as rapidly as possible without entering a ring-vortex state.
  - This means either higher disc loading (higher induced velocities to permit more rapid vertical descents) or the ability to have reversed flow through the wing/rotor system without loss of control
- Desire defined alternative solutions to avoid long vertical ascents/descents
- Short distance trips offer greater time saving potential due primarily to congestion
- Much more detailed CONOPs that include all feasibility issues

- A follow-on study has been approved to continue in FY16, with $975K in resources to include the following additional modeling and analysis.
- Demand modeling using the Transportation Systems Analysis Model (TSAM). This requires the creation of a commuter trip forecast module since TSAM currently only forecasts trips longer than 100 miles. The commuter model also requires identification of feasible access sites and level of Helipad distribution.
- Assess the effects of the flown trajectories on existing air traffic using airspace simulation. Investigate the feasibility of planning trajectories to avoid most commercial air traffic. Determine airspace capacity limits for this region.
- Implement specific concept approaches designed to meet detailed CONOPs requirements.
- Analyze the effects across mobility metrics of door to door trip speed, emissions, energy cost, and percentage of trips captured.

Los Angeles no longer requires helipads on buildings, allowing for bolder skyscraper designs

A view of downtown Los Angeles skyscrapers can be seen on Monday, Sept. 29, 2014, atop the AT&T Center building on South Olive Street during a press event at which Mayor Eric Garcetti and Fire Chief Ralph Terrazas announced that helicopter landing pads will no longer be required atop new build[...] the architecture of the city. (Photo by Dakota Smith/Los Angeles Daily News)

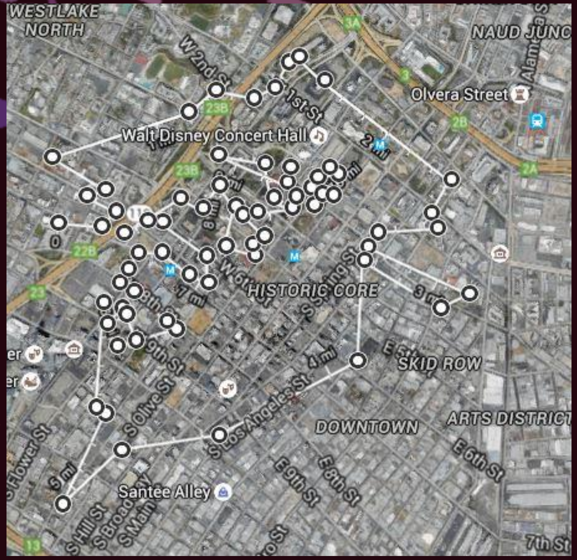
Los Angeles Daily News

Required helipads for buildings >75’ built between 1974 - 2014

Table 3: Mean Travel Time and Mean Distance for the Most Frequent Mega Commuter Flows

Top 10 Mega County Commuter Flows by Frequency

State	County	POW State	POW County	Mean Travel Time	Mean Distance
California	San Bernardino County	California	Los Angeles County	104.2	68.0
California	Riverside County	California	Los Angeles County	109.3	77.4
New York	Suffolk County	New York	New York County	114.2	64.5
Connecticut	Fairfield County	New York	New York County	104.2	60.4
New York	Orange County	New York	New York County	110.7	62.3
New Jersey	Mercer County	New York	New York County	104.6	59.3
California	Riverside County	California	San Diego County	102.3	75.5
New York	Dutchess County	New York	New York County	116.8	76.3
California	San Joaquin County	California	Alameda County	104.1	61.5
Pennsylvania	Monroe County	New York	New York County	120.5	91.1



- 30 degree ascent and decent path before reaching VTOL
- 8:1 (7˚) approach/departure surface (in flight path) from current FAA helipad restrictions
- 2:1 (45˚) transitional surface for 250’ from center of helipad (perpendicular to flight path) from current FAA helipad restrictions
- Ability to takeoff and land from all directions with a maximum of 45˚ crosswind
- 385’ vertical ascent/descent required for 500’ clearance over private land from a 200’ setback
- Block time assumptions for air travel
  - Commute to helipad: 1.9 minutes (metropolitan) or 2.8 minutes (urban, suburban)
  - Mode change: 2 minutes (assuming Uber-like operations)
  - Vertical ascent: 1.9 minutes
  - Average cruise speed multiplied by total direct distance
  - Vertical descent: 1.9 minutes
  - Mode change: 2 minutes (assuming Uber-like operations)
  - Commute to destination: 1.9 minutes (metropolitan) or 2.8 minutes (urban, suburban)
- Cruise Speed: 120 or 200 mph

Payload: 2 passengers (or 1 pilot/1 passenger in near-term) (Vehicle scale)

Range: 200 miles plus (5) takeoff and landings (average segment length of 40 miles), plus 20 minute reserve (Energy required)

Speed: Minimum threshold 150 mph cruise, 200 mph goal (Vehicle productivity)

Field Length: 50’ Diameter Helipad, (Discloading and Wing loading)

Hover: 120 second during takeoff and landing, Rapid vertical ascent/descent capability (Thrust/Weight ratio)

Wind Gust: 10 knot tailwind (Stall margin)

Community Noise: Significantly lower than Helicopters @ 100’ sideline (Tip speed) (Need to quantify) @ 500’ flyover

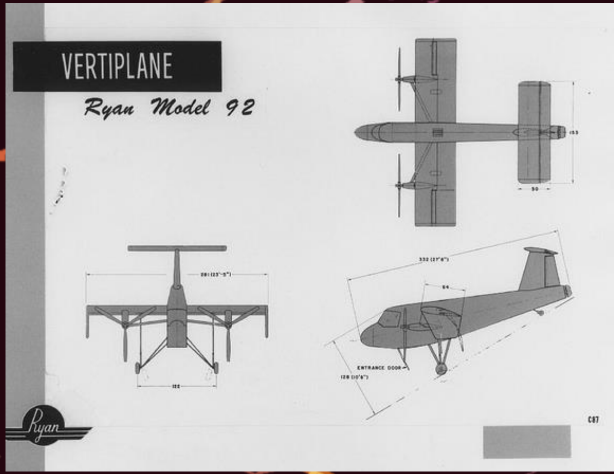
Reliability: Fewest single fault and articulating components (Vehicle utilization)

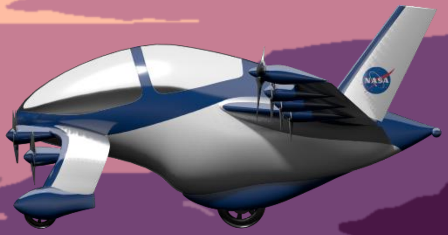
What comfort constraints should exist for ground accelerations and vehicle attitude?

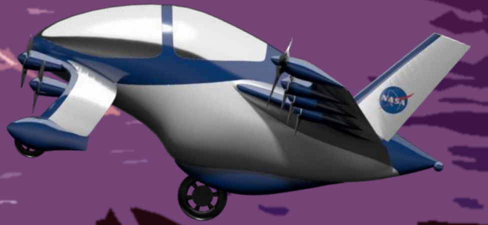
Credit: Alex Stol, Joby Aviation

Ryan Vertiplane

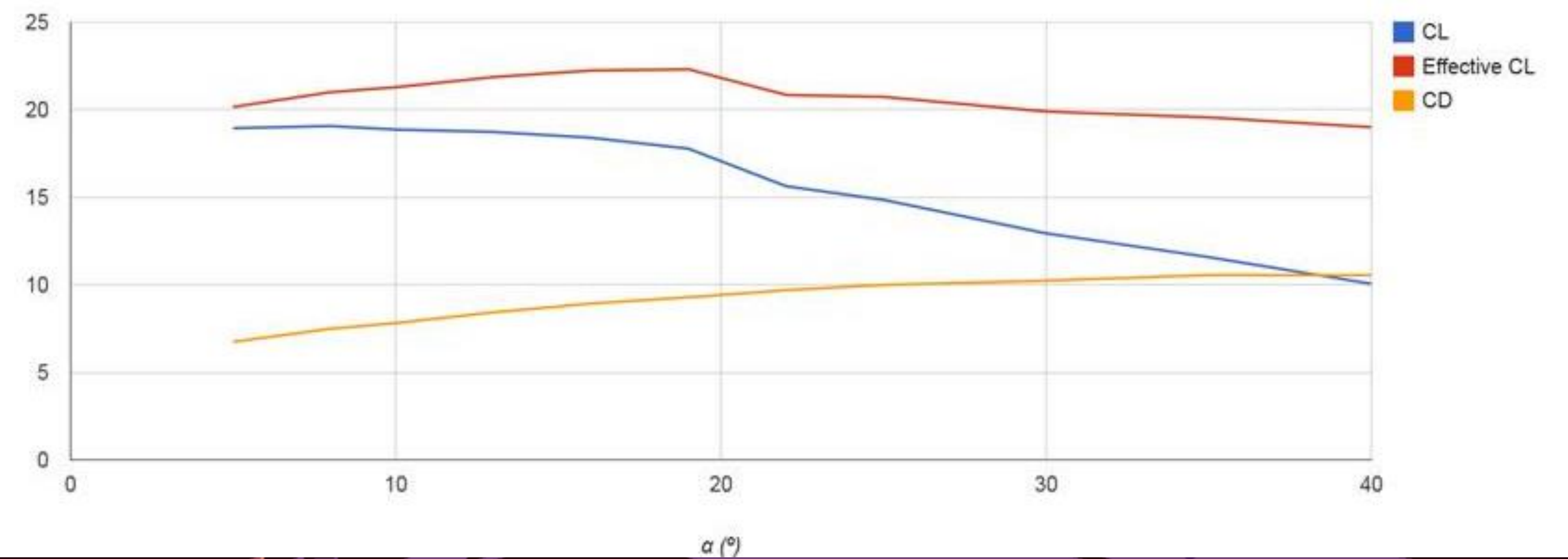
Aero-Propulsive Effects Based on Prior DEP Hardware Testing

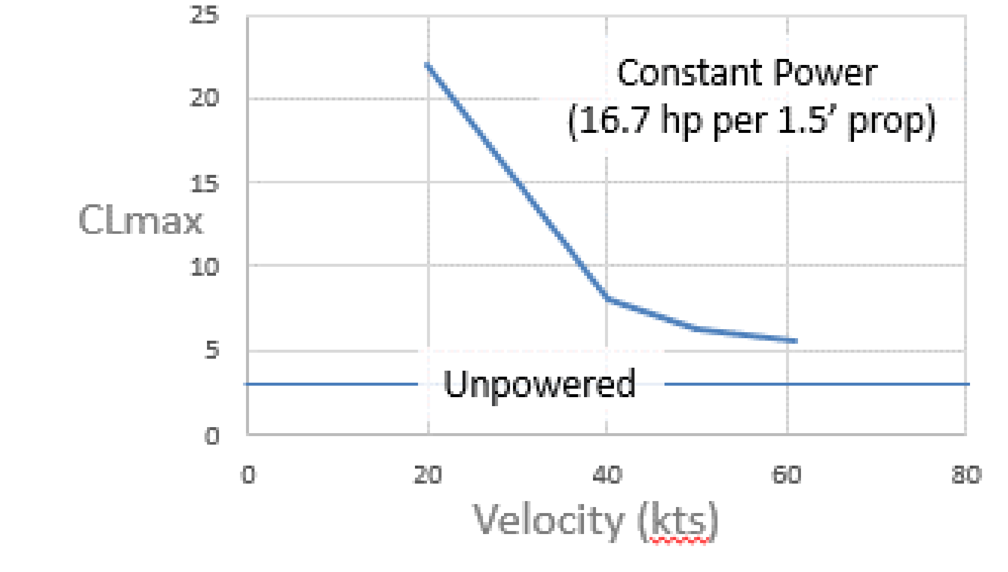






Application of Distributed Electric Propulsion to Reincarnated Vertiplane





Current DEP Wing achieves a Clmax >20 at 20 knots (with power of 10 hp/linear span foot)

Credit: Alex Stol, Joby Aviation

<u>During Departure</u>
Wing is at alpha ~5 deg (35 vehicle attitude - 30 trajectory path)
CL ~ 20, CD ~7, L/D ~ 2.9

<u>During Approach</u>
Wing is at alpha ~40 deg (10 vehicle attitude + 30 trajectory path)
CL ~ 19, CD ~10, L/D ~ 1.9

Provides both sufficient lift AND drag to achieve slow ESTOL landings.

Questions?