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Commercial Space Transportation: A Simulation and Analysis of Operations Impacts on the United States National Airspace System and Airline Stakeholders

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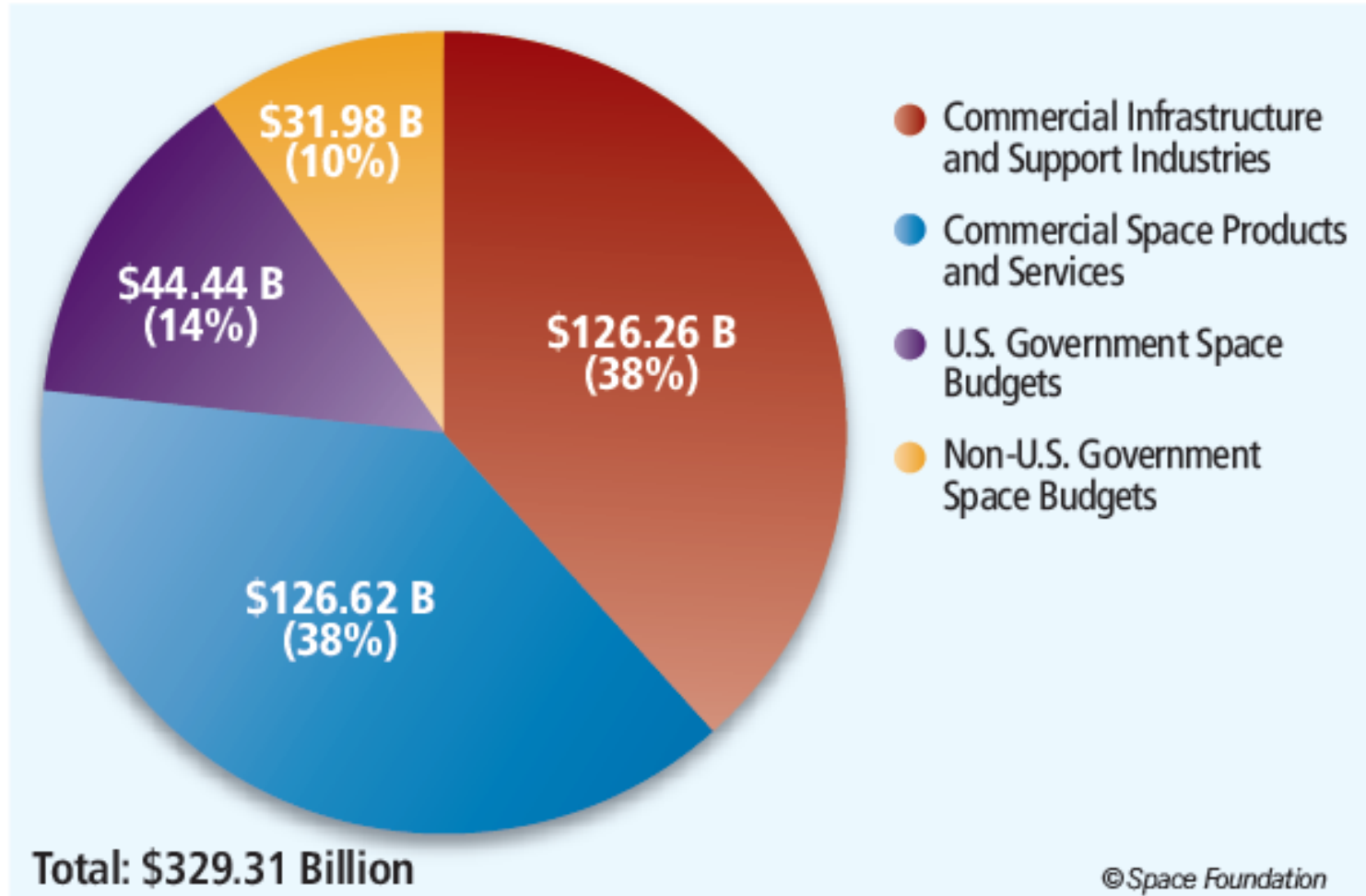
19-23 March 2018

Agenda

- Background on space launch activity
- Research problem and objective
- Methodology
- Results
- Implications
- Future research

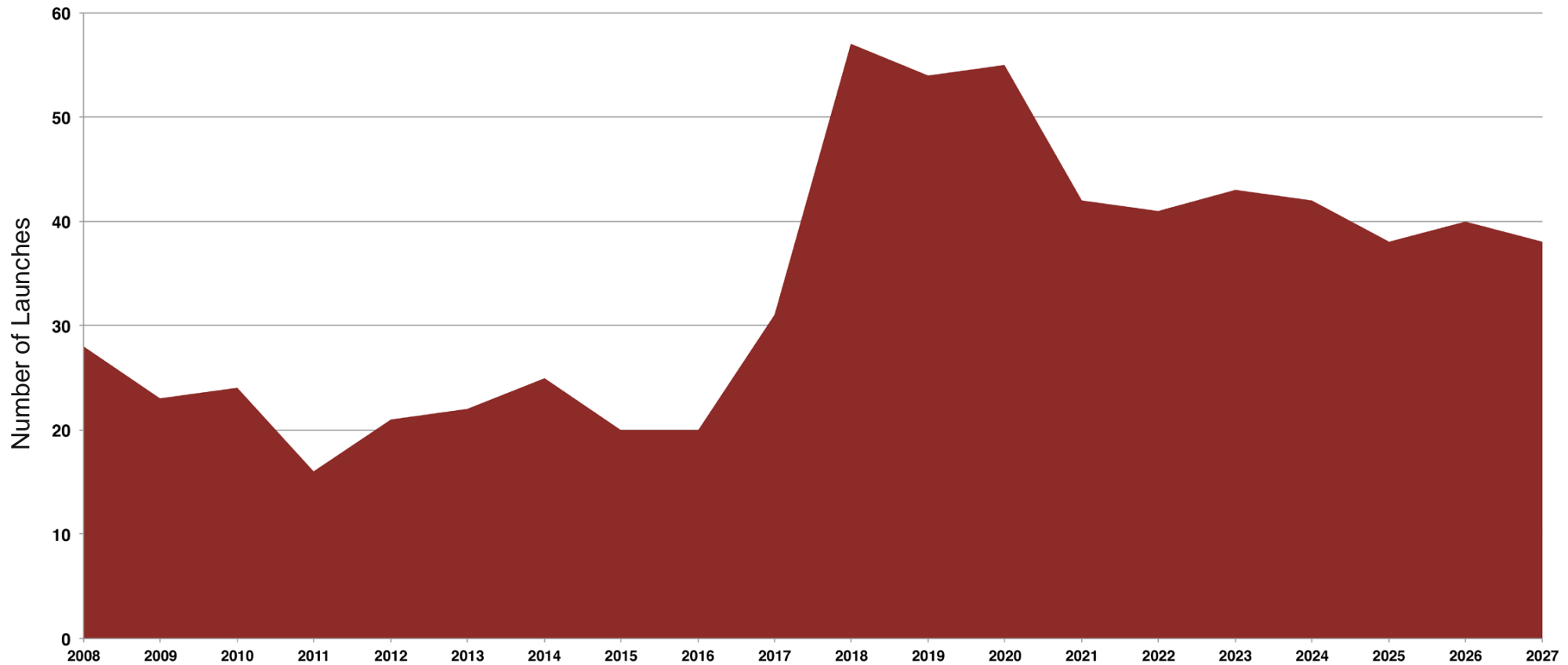


Global Space Activity, 2016



Total: 266.75€ Billion

Historical and Planned Commercial Orbital Launches



*Retrieved from 2018 AST Compendium

Suborbital Human Flight – Space Tourism

Virgin Galactic SpaceShipTwo

Received license to fly humans

\$250,000 per seat/ride

Blue Origin New Shepard

To date, no license to fly humans

Airbus Spaceplane

\$225,000 per seat/ride (Space.com 2014)



Our Research

- Stakeholders that lie outside the space industry, such as the airlines, view space transportation with intrigue, caution, concern.
 - *Commercial space efforts impacting commercial aviation.*
- Airlines apprehensive about the immediate negative effects in terms of
 - Time delays
 - Uncertainties
 - Costs
- Various studies exist on issues and challenges related to integration of commercial space transportation into national and international airspace.
 - Lack of quantitative estimates of the impacts of commercial space activities on airlines.
- Our research fills need for simulation models to analyze the potential economic impacts on these stakeholders.
 - Impacts generalizable to other areas of the world where space and aviation collide.

Select Literature Review

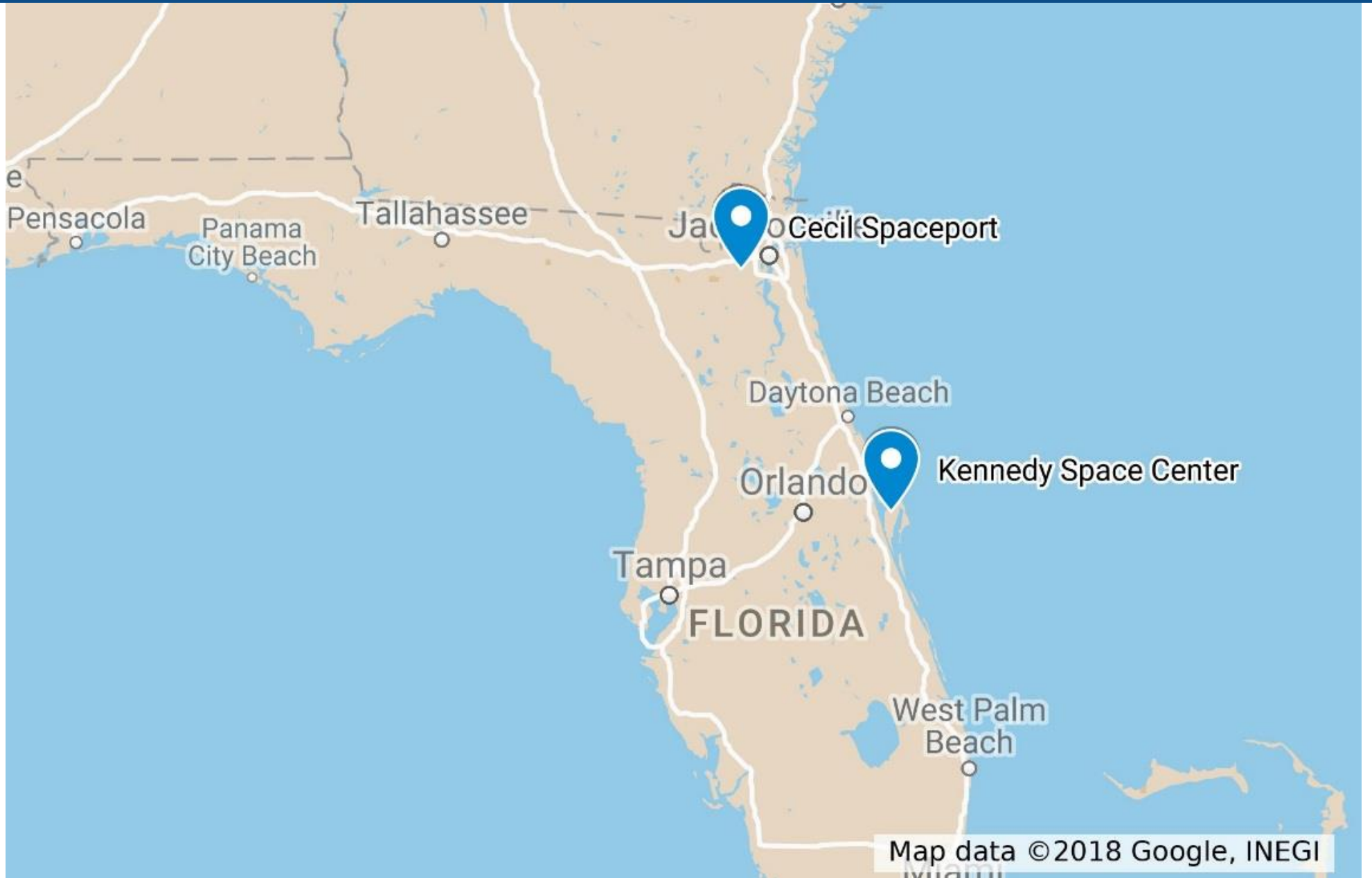
- Young and Kee (2014)
 - Quantify the NAS impact of SpaceX's Falcon 9 launch from Cape Canaveral and to identify air traffic control (ATC) practices used to minimize impact.
- Young, Kee and Young (2015)
 - Present two sets of fast time simulation scenarios to demonstrate benefits of one proposed ATC procedure over current/assess impacts to NAS.
- Tompa, Kochenderfer, Cole and Kuchar (2015)
 - Use Markov decision process model to investigate the optimal aircraft rerouting strategies/two-stage to orbit vehicle launched from Cape Canaveral.
- Colvin and Alonso (2015)
 - Simulate the effects of compact envelopes vs. traditional class of hazard area

Select Literature Review

- Luchkova, Kaltenhaeuser, and Morlang (2016)
 - Construct simulation model to generate aircraft hazard areas in European airspace along conceptual SpaceLiner flight trajectory; uses shuttle accident debris data.
- Larson, Carbon and Murray (2008)
 - Present computational tool capable of generating aircraft hazard area regions based on Space Shuttle reentry trajectories/real time state vectors/air traffic reroute due to debris.
- Srivastava, St. Clair, Zobell, and Fulmer (2015)
 - Propose a two-step approach to estimate impact of space launch or reentry on airspace; estimates extra distance and delay of impacted flights; operational cost index of delay (ground and airborne).

Methodology: Simulation Approach

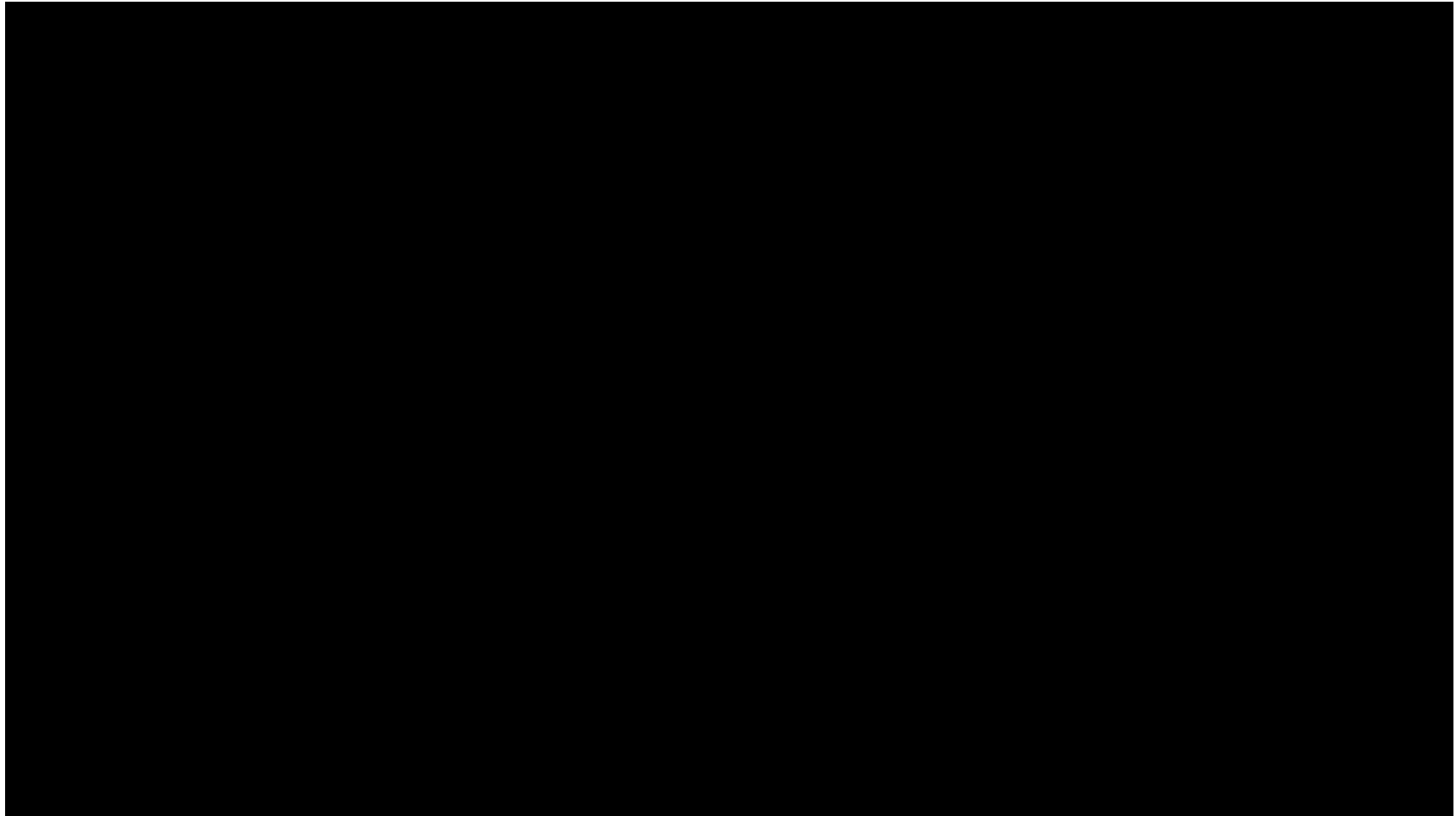
- Simulation model
 - Utilized the Total Airspace and Airport Modeler (TAAM) with Performance Data Analysis and Reporting System (PDARS) data
 - Baseline model represents existing NAS conditions including airspace sectors and air traffic routes
 - Launch models represent scenarios of integrating commercial space operations in the NAS.
 - Cecil Air and Space Port, Jacksonville, FL
 - Cape Canaveral, FL
 - NASA Kennedy Space Center
 - Cape Canaveral Air Force Station



Temporary Flight Restrictions (TFRs) and Special Use Airspace (SUA)



Air Traffic – Normal vs Launch Activity



Simulation Scenario: Cecil Air and Space Port

Location

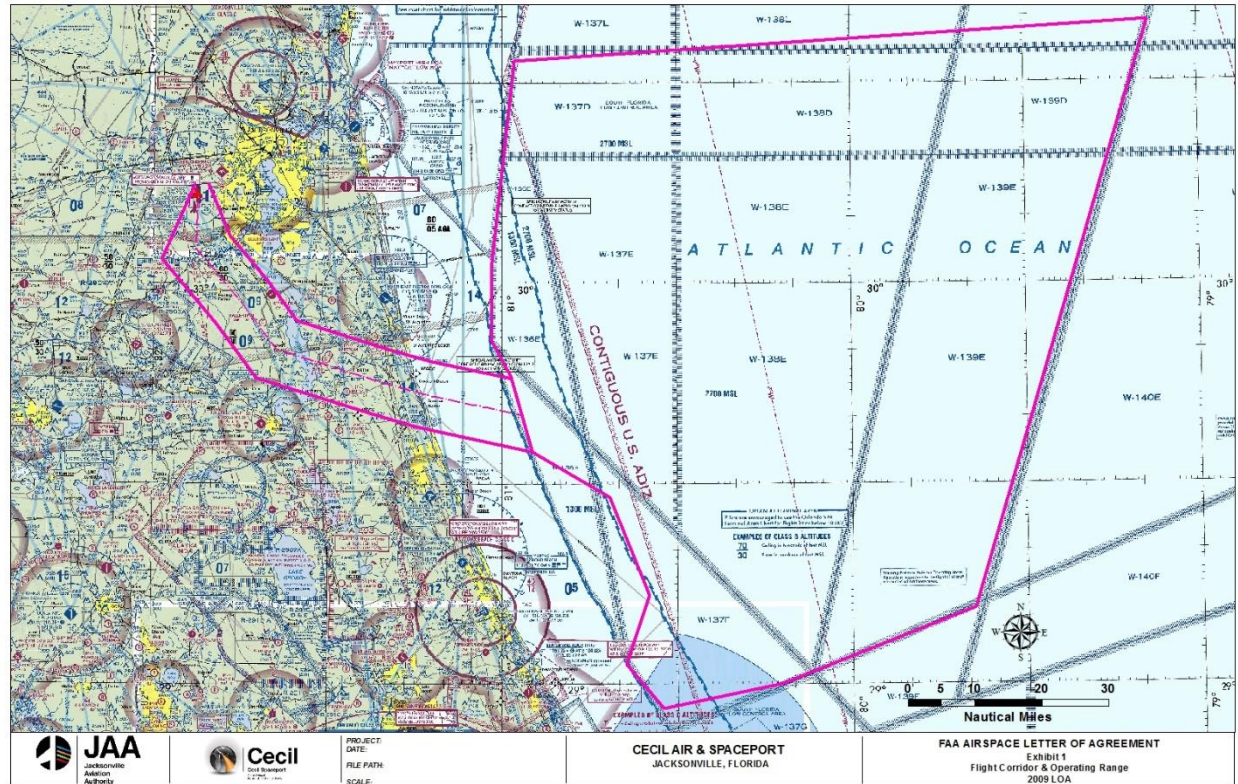
- Cecil Air and Space Port, Jacksonville, FL

Vehicle

- Virgin Galactic SpaceShipTwo (SS2)

Mission Profile

- Horizontal takeoff and landing
- Carrier aircraft/spacecraft separation at 15km



Cecil
Cecil Airport



PROJECT:
DATE:
FILE PATH:
SCALE:

CECIL AIR & SPACEPORT
JACKSONVILLE, FLORIDA

FAA AIRSPACE LETTER OF AGREEMENT
Exhibit 1
Flight Corridor & Operating Range
2009 LOA

Simulation Scenario: Cape Canaveral

Location

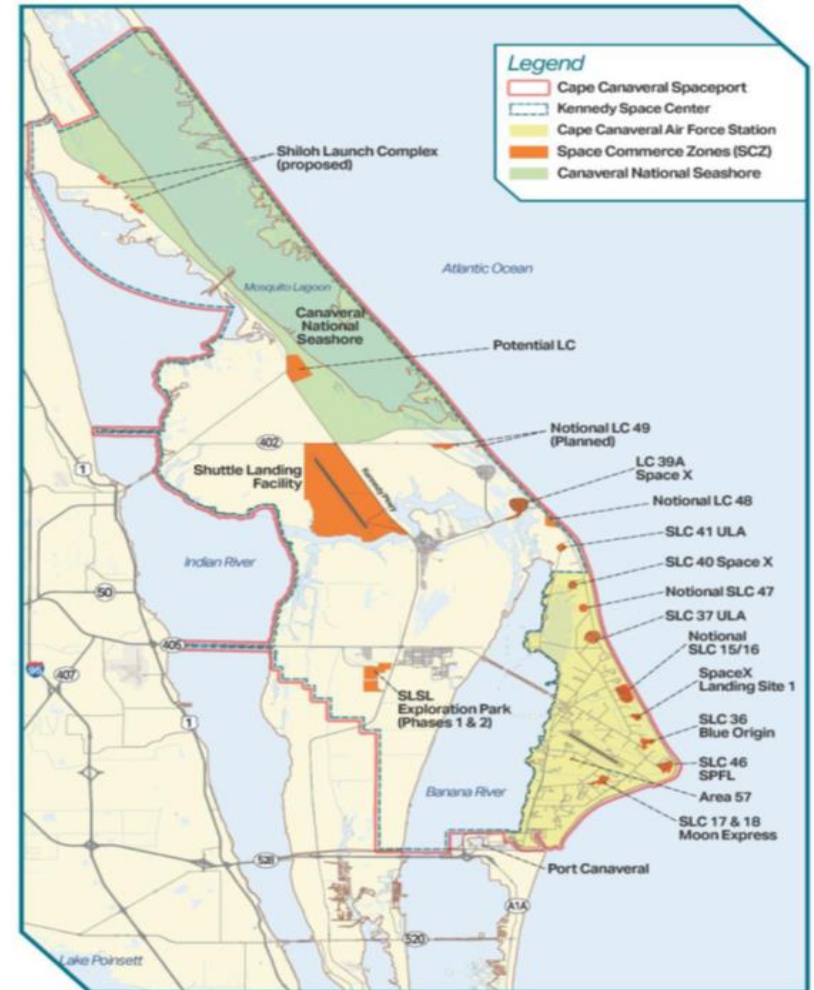
- **Cape Canaveral, FL**
(Kennedy Space Center and Cape Canaveral Air Force Station)

Vehicle

- Delta IV Heavy

Mission Profile

- Vertical takeoff
- Air traffic impact is independent of vehicle, for example, Falcon 9 vs. Delta IV.



Source: AECOM/Cape Canaveral Spaceport Master Plan 2017

TAAM Simulation Set-Up

Scenarios	May 2, 2017	2027	2037
Baseline	Actual Air Traffic	Forecasted Air Traffic ²	Forecasted Air Traffic
Cecil Launch	Simulated Air Traffic	Forecasted Air Traffic	Forecasted Air Traffic
Cape Canaveral Launch	Actual Air Traffic with Embedded Impact by <i>Delta IV Heavy</i> Launch on April 18 ¹	Forecasted Air Traffic	Forecasted Air Traffic

Notes:

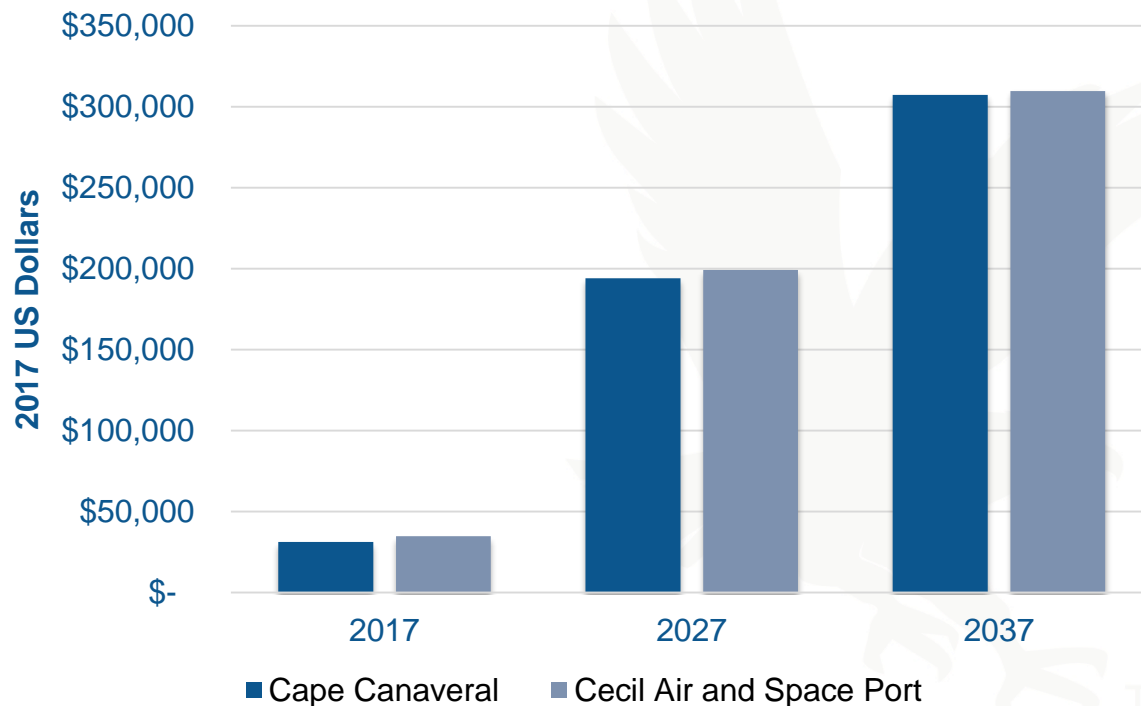
- Simulation includes all air traffic impacted by the launch.
- May 2, 2017 represents the busiest air traffic conditions.

¹ PDARs data retrieved for Delta IV Heavy launch on April 18, 2017; overlaid and matched to the baseline data of May 2, 2017.

² Future air traffic volume simulated using FAA forecast data for the number of IFR flights handled by both ZJX and ZMA Air Route Traffic Control Centers. Air traffic volume was estimated to grow by 15% from 2017 to 2027, and 28% from 2017 to 2037.

Simulation Preliminary Results

Scenario Fuel Cost Increase (based on \$1.51/gallon - €0.32/liter)

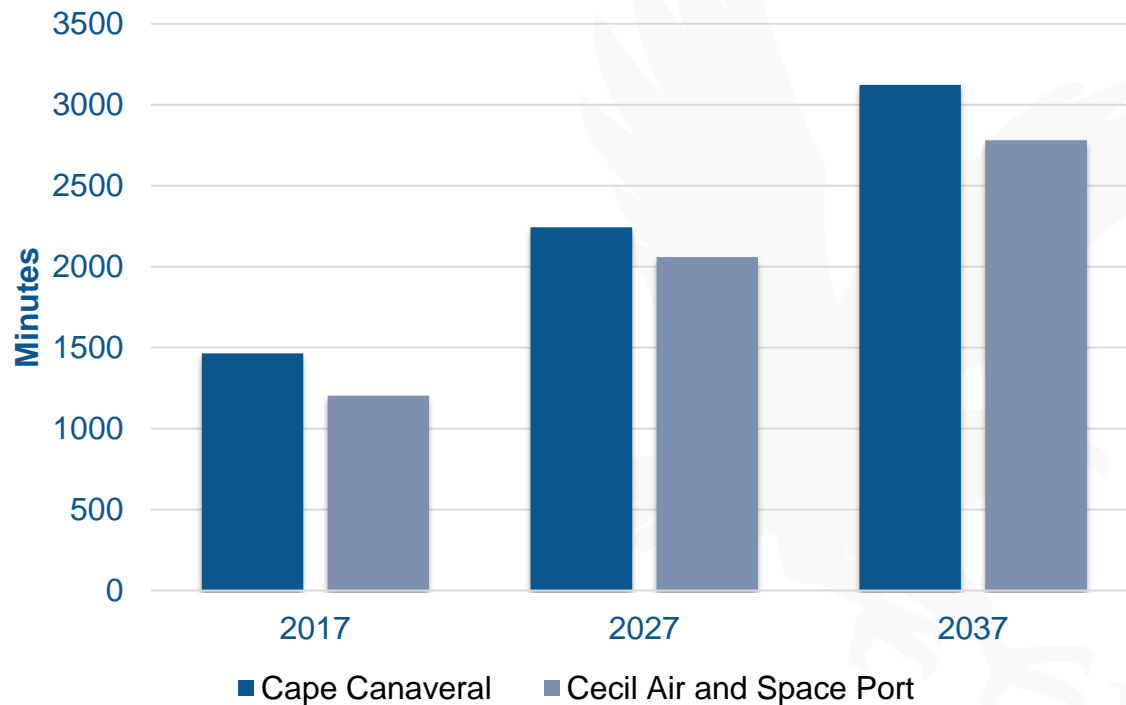


- TAAM Dynamic Fuel Option was used
- US jet fuel cost for May 2, 2017 was used (Baseline).
- Similarity in results is expected.
- Airspace disturbance is very similar in both space and time for both scenarios.

- Each column represents the impact of one launch.

Simulation Preliminary Results

Simulated Cumulative Flight Delay (min)



- Flight delays can be used to quantify and understand the impact on commercial airline operations.
- Under current ATC procedures, impact is expected to increase with air traffic.

- Each column represents the impact of one launch.

Implications

- Commercial space efforts now impacting commercial aviation.
- Preliminary results indicate impacts to airlines can be significant, particularly as frequency of launch/return activities increase with increased aviation traffic.
 - Impacts may be greater if no advanced warning, i.e., unexpected debris.
 - Implications for airlines' network and schedule planning decisions, as well as aviation authority regulations, standards, procedures, among others.
- Results are generalizable anywhere in the world where commercial space and aviation will be vying for the same airspace.
 - UK, Canada, Curaçao, UAE, New Zealand, etc.

Future Research

- Solutions must be developed whereby full integration of commercial space traffic with aviation traffic will allow for a safe and efficient flow.
 - Discovery and implementation of these solutions are the next step.
- Other future research should include analyses of
 - Additional costs to airlines due to crew time, maintenance, etc.
 - Impacts to other key stakeholders, such as airports and operations, for direct and indirect consequences of launch/return activities.
 - Consequences of forecasted increase in launch and return activities as well as changes to air traffic control procedures (simulation based on current procedures).



Thank you for your time.

Appendix

Cecil Spaceport: Airspace Agreement 2009

- Cecil Spaceport approved for Concept X and Z RLVs
- License renewed in 2015 for 5 years.
- RLV operations approved:
 - 2 flights/week on Wednesdays and Saturdays only prior to 0900 local
 - Not be scheduled when military operations, Cape Canaveral activities or major events like Daytona 500 Sun-n-Fun Fly-In, etc.
 - May be canceled due to weather or increased air traffic
 - VQQ TWR open and Class D airspace activated during RLF operations
 - RLV departures authorized on RWY 18L; arrivals only on RWY 36R

Concept X RLV Cecil-Specific Operations

Passengers and/or scientific payloads

- First stage of small LEO satellite delivery
- Cecil/JAA can support a max of 48 launches and landings a year

Operational Procedure

- Runway 18L-36R
- Jet powered takeoff to Offshore Warning Area (OWA)
 - o 60 miles offshore
 - o 40,000 – 55,000ft above MSL
- Rocket powered till apogee
 - o 330,000ft above MSL
- Landing with jet engine assistance or as glider

Concept Z RLV Cecil-Specific Operations

Reusable or expendable launch vehicle

- Cecil/JAA can support a max of 4 launches and landings a year

Operational Procedure

- Runway 18L-36R
- Jet powered takeoff to Offshore Warning Area (OWA)
 - 60 miles offshore
 - 40,000 – 55,000ft above MSL
- Components detach
- Carrier returns and lands using jet engines
- Rocket powered component completes mission
 - Returns and lands as a glider
 - Or is expended in the Atlantic, 100 miles east of continental US

Airspace Agreement 2009: Preflight Activity Schedule

- (1) CSOO shall contact ZJX Missions, JAX, VQQ TWR, and FACSFACJAX:
 - (a) NLT 3 hours prior to a scheduled flight to provide operational status
 - (b) NLT 30 minutes prior to a scheduled flight to provide operational status.
 - If communications cannot be established, or if, in the opinion of ZJX, a potential hazard to persons or property exists, the flight operator shall delay the flight until mitigated.
 - (c) NLT 5 minutes prior to a scheduled flight for flight approval. If communications cannot be established, ...delay the flight until the hazard is mitigated and/or communications can be made.
 - (d) Immediately regarding any delay or when operations are completed, cancelled, rescheduled or terminated.

Airspace Agreement 2009: Preflight Activity Schedule

(2) ZJX Missions shall:

(a) NLT 3 hours prior to a scheduled flight, coordinate the proposed launch time with ZMA Missions.

(b) NLT 5 minutes prior to a scheduled flight, ensure all non-participating aircraft under ZJX and ZMA control remain clear of the RLV Operations Area until notified by the JAA/CSOO that operations have been completed, cancelled, rescheduled or terminated.

(c) Notify the CSOO immediately if any non-participating aircraft will penetrate the RLV Operations Area and/or when this no longer constitutes a safety concern.

(3) FACSFACJAX shall ensure, NLT 5 minutes prior to a scheduled flight, the RLV Operations Area is cleared of non-participating aircraft under their control.