Range Safety Implications For Brownsville, Texas Launches To Earth Orbit

On 4 August 2014, Space Exploration Technologies (SpaceX) founder Elon Musk announced his company's decision to build a rocket launch facility at Boca Chica Beach near Brownsville, Texas. This paper focuses on SpaceX launches into low Earth orbit (LEO) from this facility and associated trajectory restrictions from likely range safety standards. Payloads launched from Brownsville may remain in LEO, or they may reside there only briefly before departing for more distant destinations such as geosynchronous Earth orbit (GEO), cislunar space, or interplanetary space.

The rockets SpaceX intends to launch into LEO from Brownsville are the *Falcon 9* and *Falcon Heavy* per the FAA's environmental impact statement [Ref. 1, p. ES-1]. According to the statement [Ref. 1 p. ES-3], "All launch trajectories would be to the east over the Gulf of Mexico." One example *Falcon Heavy* trajectory plot following a Brownsville launch appears in the statement [Ref. 1, p. 2-11] and is accompanied by "Warning Area" regions in the Gulf of Mexico, but hazards associated with these areas are not disclosed. *Falcon 9* first stage impact is "approximately 550 miles downrange" [Ref. 1, p. 2-12], but *Falcon Heavy* first stage and side booster [Ref. 1, p. 2-3] impact locations are not provided. The statement does disclose, "The second stage would go into orbit with the payload." [Ref. 1, p. 2-12], an assertion assumed to apply to both *Falcon 9* and *Falcon Heavy*. In event of launch vehicle malfunction or abort, special provisions are made according to the following excerpt [Ref. 1, p. 2-12].

> The launch vehicle would be equipped with either a thrust termination or a destructive flight termination system, or both, in the event the vehicle varied from the planned trajectory. The vehicle would break up and debris could land in the Gulf of Mexico.

If SpaceX conforms to the FAA's environment impact statement and is held accountable to range safety standards under which humans were launched into LEO aboard the Space Shuttle, the allowable trajectory envelope from Brownsville will be highly restricted. Space Shuttle standards require even remote Pacific islands to be well removed from the nominal ground track in case LEO cannot be achieved. The *Falcon 9* and *Falcon Heavy* must be held to a similar restriction should their second stages malfunction short of LEO speed (an "underspeed" condition in Space Shuttle abort terminology). In many cases, such underspeeds would cause second stage and payload debris to impact Earth much farther downrange than the Gulf of Mexico. Marginal underspeed scenarios just short of LEO could have debris impacting along "footprints" hundreds of miles long nearly a full orbit after launch.

Range safety implications from three Brownsville launch scenarios targeting circular LEO about 296 km in height are explored herein. Launch trajectories to be used by *Falcon 9* and *Falcon Heavy* are assumed to be adequately approximated by Mode 1 Powered Explicit Guidance (PEG-1) used in Space Shuttle launches to achieve LEO. From a map in the FAA's environmental impact statement [Ref. 1, p. 1-3], a Brownsville launch site location at 25.996° N Lat; 97.151° W Lon is inferred. Launch time for the three scenarios is arbitrarily fixed at 12:00 UT on 22 August 2014.

A frequent *Falcon 9* LEO destination is the International Space Station (ISS). Efficient launches to ISS can occur only when Earth rotation brings Brownsville close to the ISS orbit plane. These planar launch windows require *Falcon 9* to depart Brownsville in a northbound or southbound

direction in order to match ISS orbit motion in a plane inclined about 51.6° to Earth's equator. Figures 1 and 2 illustrate ground tracks from Brownsville launch through LEO insertion at 51.6° inclination approximately 10 minutes later. These tracks extend through the first two orbits after launch.

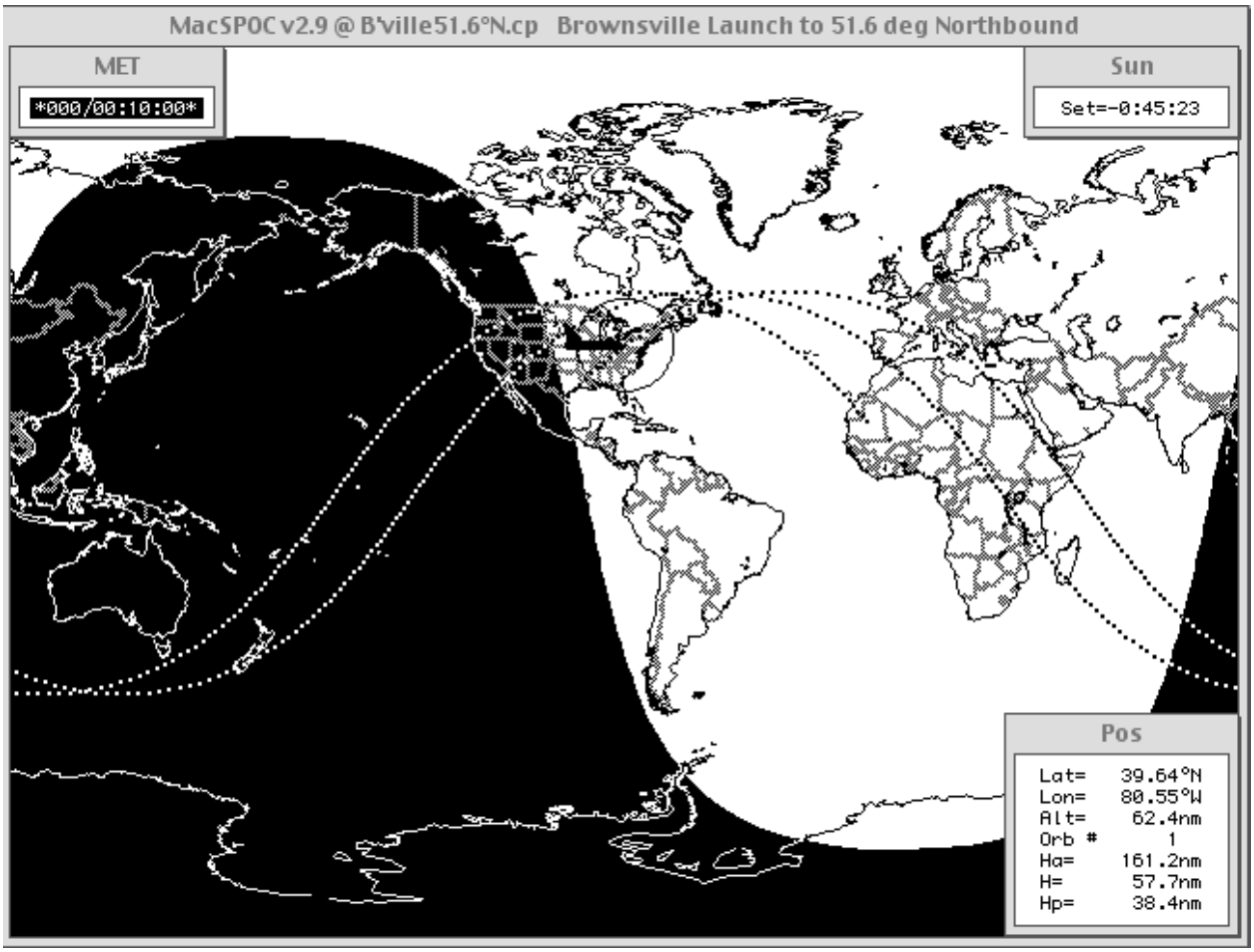

Figure 1. Ground track points following a northbound Brownsville launch into a 296 km LEO at 51.6° inclination are plotted as square markers at 30-s intervals. Location data in the Pos window pertain to the Space Shuttle Orbiter icon's "nose" 10 min after launch per the Mission Elapsed Time (MET) window. The shaded area is nighttime on Earth's surface, and orbital sunset will next occur 55 min 23 s after launch per the Sun window. Range safety concerns in eastern North America, western Europe, northeastern Africa, and New Zealand are evident along the first orbit.

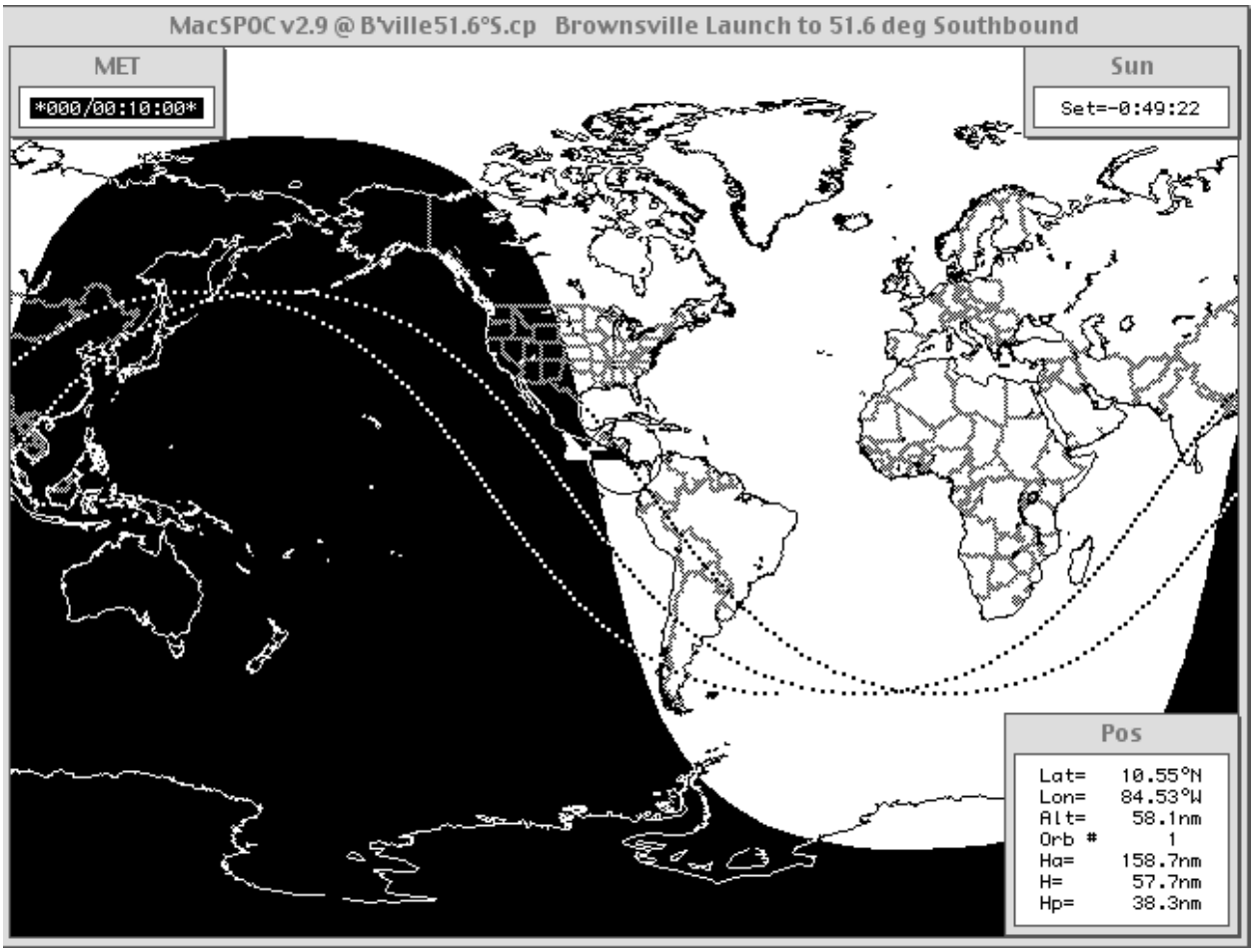

Figure 2. Ground track points following a southbound Brownsville launch into a 296 km LEO at 51.6° inclination are plotted as square markers at 30-s intervals. Location data in the Pos window pertain to the Space Shuttle Orbiter icon's "nose" 10 min after launch per the Mission Elapsed Time (MET) window. The shaded area is nighttime on Earth's surface, and orbital sunset will next occur 59 min 22 s after launch per the Sun window. Range safety concerns in Central America, South America, eastern Asia, and the Aleutian Islands are evident along the first orbit.

Range safety concerns associated with northbound and southbound Brownsville launches to ISS are of such magnitude they are unlikely to be accepted by the FAA or other regulatory authorities. Likewise, it is doubtful NASA would approve such launches for its astronauts should SpaceX win an ISS crew logistics contract.

From the standpoint of range safety, likely the best Gulf of Mexico exit for LEO-bound Brownsville launches would be a narrow corridor over the Straights of Florida. Achieving this geometry would entail a southbound launch at 26.3° inclination as illustrated in Figure 3.

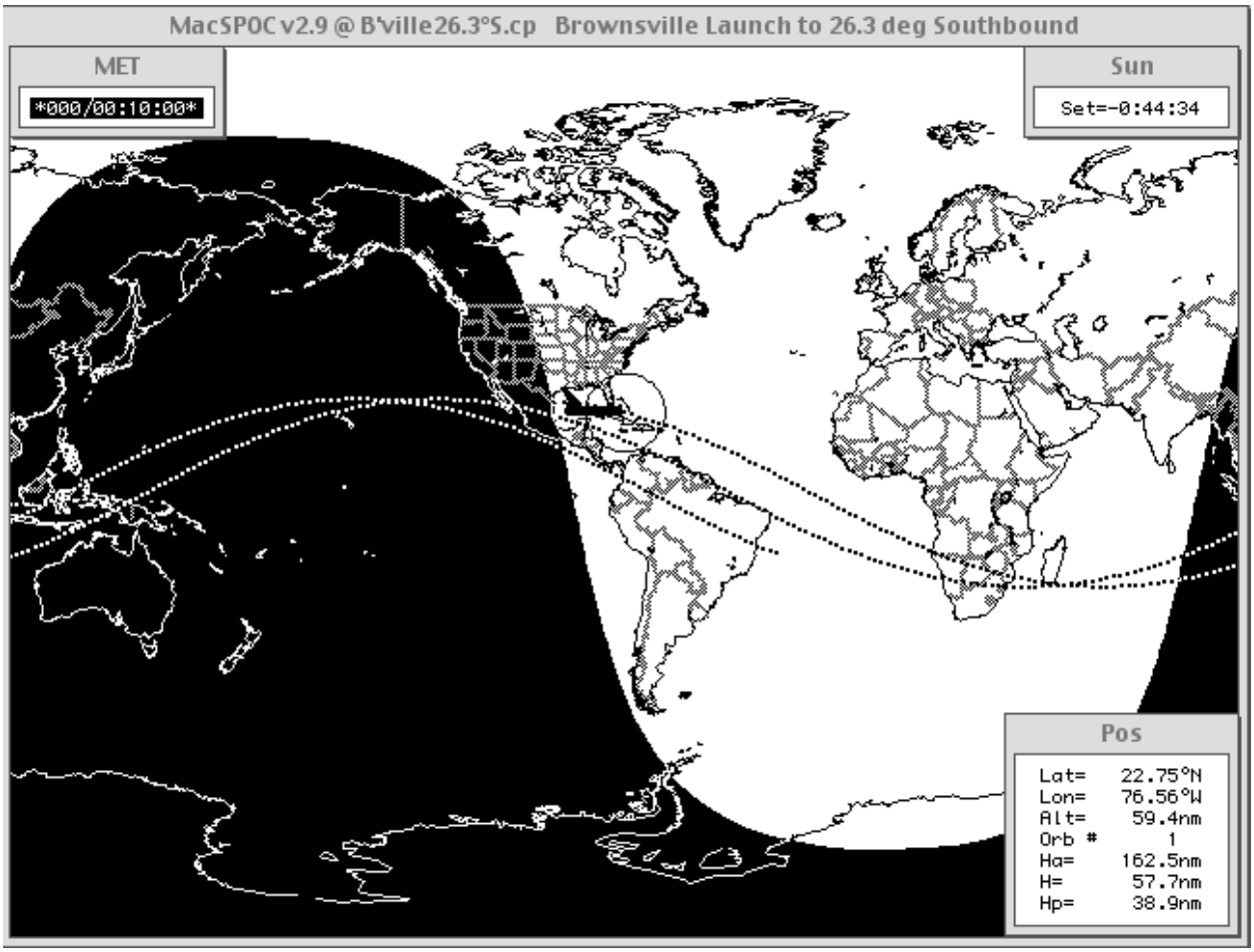

Figure 3. Ground track points following a southbound Brownsville launch into a 296 km LEO at 26.3° inclination are plotted as square markers at 30-s intervals. Location data in the Pos window pertain to the Space Shuttle Orbiter icon's "nose" 10 min after launch per the Mission Elapsed Time (MET) window. The shaded area is nighttime on Earth's surface, and orbital sunset will next occur 54 min 34 s after launch per the Sun window. Range safety concerns in southern Africa, Madagascar, Indonesia, and the Hawaiian Islands are evident along the first orbit.

Figure 4 is a smaller scale map illustrating ground tracks from all three Brownsville launch scenarios in greater detail during the first ten minutes of flight. The southbound 26.3° inclination ground track is similar to the *Falcon Heavy* launch trajectory example from the FAA's environment impact statement [Ref. 1, p. 2-11].

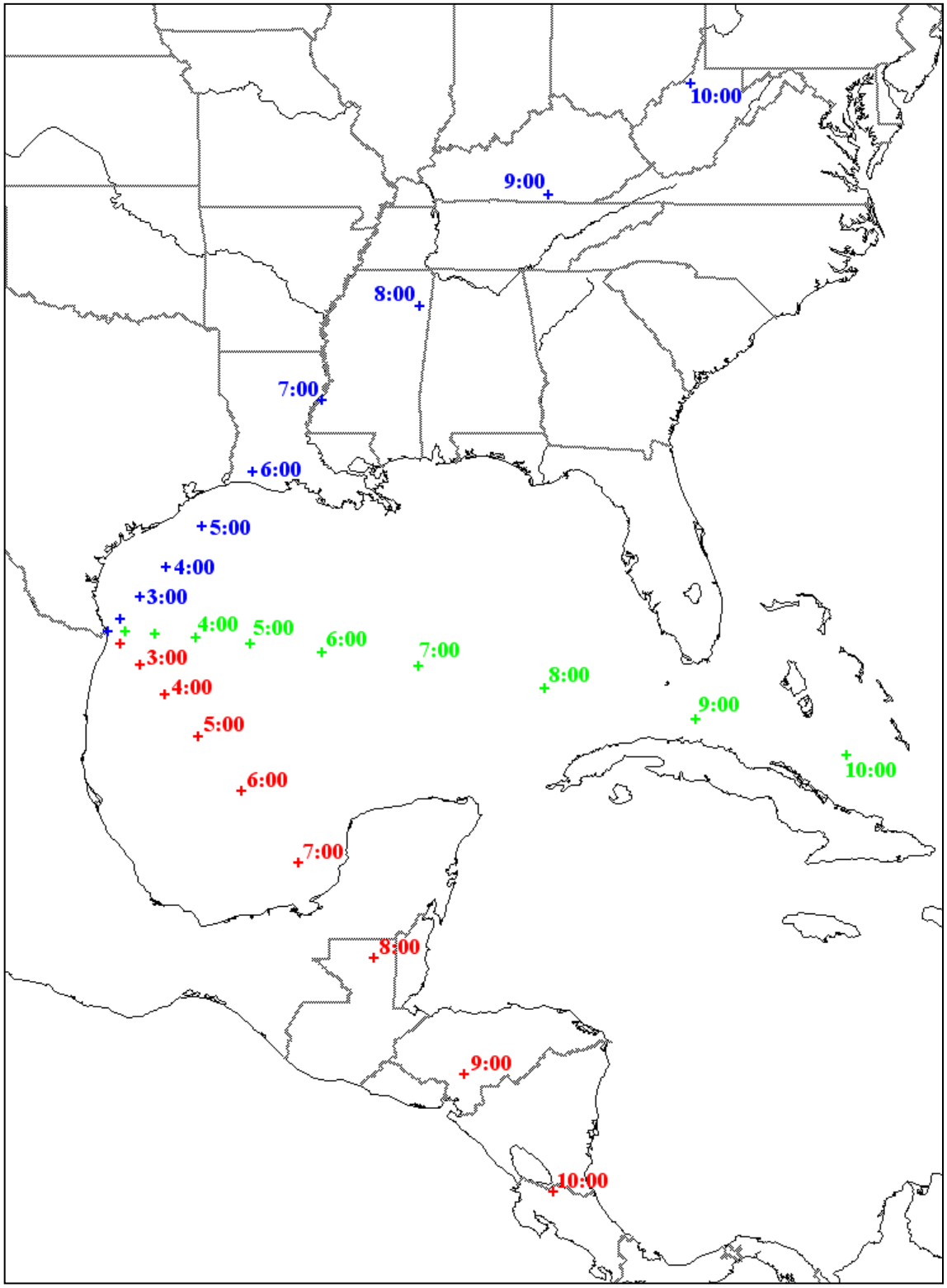

Figure 4. Ground tracks resulting from Brownsville launches targeting northbound LEO at 51.6° inclination (blue + markers), southbound LEO at 51.6° inclination (red + markers), and southbound LEO at 26.3° inclination (green + markers) are annotated with time since launch in min:s format. The first marker displaced from Brownsville is 2:00 after launch.

Even if southbound 26.3° inclination launches from Brownsville are permitted, very little deviation from this ground track would trigger range safety concerns for Florida or the West Indies. Addressing these and other such concerns would presumably require demonstrated airline-like reliability during regular launch operations over many years.

The tight launch trajectory envelope out of Brownsville does not bode well for flexible operations. Rendezvous in LEO will be possible only for satellites near 26.3° inclination. Reaching GEO will be practical, but launch windows targeting cislunar and interplanetary destinations will be only a handful of minutes in duration. Because some interplanetary destinations require launch into LEO at inclinations considerably greater than 26.3° [Ref. 2, Figure 5], initiating those missions from Brownsville will not be practical. At times, destinations like Mars will be unavailable to Brownsville launches without propulsive penalties or transit delays. Other launch locations would not be subject to those penalties or delays.

In conclusion, the decision to launch rockets from the vicinity of Brownsville, Texas targeting destinations in LEO and beyond appears highly problematic if historic range safety standards apply. Some of these standards appear to be absent from considerations documented in the FAA's environmental impact statement for this launch site. At best, full assessment of range safety standards would permit only a narrow range of departure ground tracks from Brownsville.

References

1. FAA Office of Commercial Space Transportation, *Draft Environmental Impact Statement SpaceX Texas Launch Site*, FAA, HQ-0092-K2, April 2013.*
2. Adamo, D. R., "Trajectory Challenges Faced By Reusable Infrastructure In Earth Orbit Supporting Multiple Departures For Mars", *The Space Show Classroom*, 2013.†

* This document may be downloaded from http://www.faa.gov/about/office_org/headquarters_offices/ast/environmental/nepa_docs/review/documents_progress/spacex_texas_launch_site_environmental_impact_statement/media/SpaceX_Texas_Launch_Site_Draft_EIS_V1.pdf (accessed 24 August 2014).

† This document may be downloaded from http://spaceshowclassroom.files.wordpress.com/2013/11/multiplemarsdeparturesr1.pdf (accessed 25 August 2014).