Ocean Engineering 104 (2015) 119–128

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Voyage across Ligeia Mare: Mechanics of sailing on the hydrocarbon seas of Saturn's Moon, Titan

Ralph D. Lorenz *

Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA

ARTICLE INFO

Article history:
Received 13 July 2014
Accepted 30 April 2015
Available online 30 May 2015

Keywords:
Drifting Buoy
Planetary exploration
Titan
Force balance

ABSTRACT

Like sailing ships, drifting buoys and icebergs on the seas of Earth, the motion of a capsule floating on the cold methane/ethane seas of Saturn's moon Titan results from the balance of aerodynamic and hydrodynamic forces above and below the 'waterline'. This balance is evaluated in the context of a NASA proposal to send such a capsule to perform oceanographic and other measurements on the ~400 km wide Ligeia Mare in 2023. Taking liquid and air density into account (the sea:air density ratio on Titan is ~100, compared with ~800 on Earth) in the drag balance, it is expected that the vehicle will drift at a fraction f of the near-surface windspeed with f~0.08–0.18. Consideration of wave effects suggests a correction of the form $f' \sim f(1+0.7U_{10}^4)$. Winds of about 0.3 m/s are expected in this season (late Northern summer), and drift trajectories using two different global circulation models are computed. It is expected that the vehicle would encounter the coastline after drifting ~150 km over 2–10 Titan days (~32–150 Earth days.)

1. Introduction

Saturn's giant moon Titan (Lorenz and Mitton, 2010; Lorenz and Sotin, 2010) has lakes and seas of liquid hydrocarbons, predominantly in its polar regions. Titan is 5150 km in diameter (larger than the planet Mercury) and has a thick 1.5 bar nitrogen atmosphere. Titan's temperatures (94 K at the surface) allow methane and ethane to exist as a liquid.

Mapping by the Cassini spacecraft, which is in Saturn orbit but makes close passes of Titan every few weeks, revealed (Stofan et al., 2007) hundreds of ~20 km lakes around Titan's north pole, in contrast to the equatorial regions (visited briefly by the Huygens probe's parachute descent to a dry riverbed in 2005) which are deserts hosting vast expanses of sand dunes. Later, three bodies of liquid large enough to merit designation as 'seas' were identified (Fig. 1). One major south polar lake is known, and a few transient areas of liquid have been spotted at low latitudes.

The northern seas, in decreasing order of size, are Kraken Mare, Ligeia Mare and Punga Mare (the IAU Committee on Planetary Nomenclature designates Mare (seas) on Titan with the names of terrestrial sea monsters) are prime targets for future exploration, not only as reservoirs of organic material of astrobiological interest, but as laboratories for air:sea exchange and other oceanographic processes (for a brief review of Titan's seas, see Lorenz, 2013). This thinking shaped a 2008/2009 NASA/ESA mission study, the Titan Saturn System Mission (TSSM) concept, which featured an orbiter, a hot air balloon, and a 'lake lander' which would operate for a few hours, but this expensive multi-element 'flagship' mission was quickly shelved. A lake lander mission was also evaluated briefly in the context of the US Planetary Science Decadal Survey (JPL, 2010; Space Studies Board, 2012).

Prior to the Decadal Survey, however, a modest yet innovative concept was originated in the framework of a NASA DSMCE (Discovery Scout Mission Capability Enhancement) study solicited in 2007. This concept, led by Ellen Stofan of Proxemy Research, is the Titan Mare Explorer (TiME), which would feature a capsule delivered by parachute to Ligeia. In original concept this vehicle was notionally to have been launched in 2015 to arrive in 2022: this late northern summer arrival date would permit the Earth to be visible from Ligeia's high northern latitude, allowing a direct-to-Earth data transmission, without requiring an expensive orbital relay. The concept (Stofan et al., 2013) was developed further and proposed (for a 2016 launch with 2023 arrival) to the NASA Discovery 2010 mission call by a Proxemy/Lockheed Martin/Applied Physics Laboratory team, and was one of three missions (out of 28 proposals) selected for a $3 million Phase A study. This paper documents one aspect of that study, namely the mechanics of the vehicle's traverse of an extraterrestrial sea.

We first briefly describe the target location and environment, and the TiME spacecraft and its goals and scientific payload. We

* Tel.: +1 443 778 2903; fax: +1 443 778 8939.
E-mail address: Ralph.lorenz@jhuapl.edu

http://dx.doi.org/10.1016/j.oceaneng.2015.04.084
0029-8018/

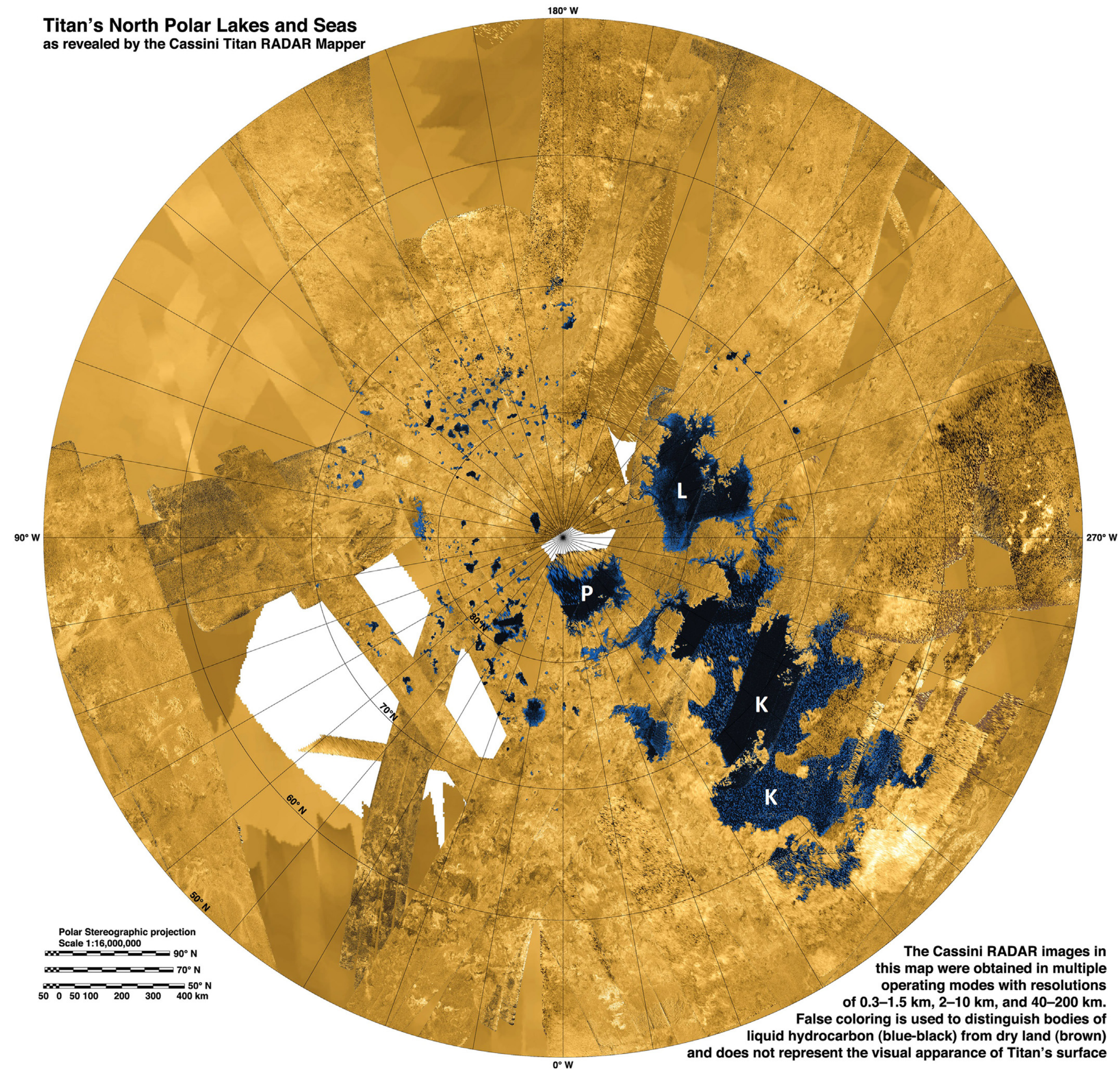

Fig. 1. A map of Titan's northern polar regions – blank areas are not yet imaged by radar. The low radar reflectivity of the seas and lakes is apparent, as is the somewhat complex outline of the seas Punga (P), Ligeia (L) and Kraken (K).

then discuss how the vehicle's motion in the sea relates to the windspeed, and consider wind predictions and the resultant voyage across Ligeia.

2. Target – Ligeia Mare

The nominal target of the TiME mission is Ligeia Mare, the second-largest of Titan's seas. This was chosen because at the time (~2008) it was the best-mapped of Titan's three seas. The preponderance of seas in the northern hemisphere is thought to be the result of the astronomical configuration of Titan's seasons in the current epoch, which has the result that the northern summer is less intense but longer in duration than that in the south (Aharonson et al., 2009). This results in a longer 'rainy season' in the north, such that methane and ethane accumulate there. This seasonal configuration lasts several tens of thousands of years, much like the Croll-Milankovich cycles that play a part in the Earth's ice ages and the Martian polar layered terrain. This picture of a drying south and accumulating north is consistent with the ria coastlines of Ligeia (Fig. 2) which suggest valleys being flooded by rising sea levels (e.g. Wasiak et al., 2013; Sotin et al., 2012), and with the kidney-shaped outline, shallow (and possibly declining) depth of Ontario Lacus in the south (Fig. 1) – see Hayes et al., (2010, 2011).

The energetics of the climate system are such that only one or a few meters of liquid might migrate from south to north (or vice versa) during the seasonal cycle of 29.5 Earth years (Aharonson et al., 2009). However, the scaling relationship between the horizontal extent of lakes on Earth and their depth (roughly 1 m depth per km of extent,