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Autonomous Emergency Landing for Fixed-Wing Aircraft with Energy Constrained Closed-Loop Prediction

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Introduction

- ❑Complete loss of thrust can result from bird strikes, mechanical failures, or fuel exhaustion.
- ❑Gliding flight situations are dangerous and require rapid decision-making.
- ❑Pilot must consider aircraft energy, runway locations, max/min landing speed, and danger to individuals on the ground.
- ❑Pilots on US Airways Flight 1548 only had 16s to act before the best landing site was out of range [1].
- ❑Autonomous emergency landing algorithms are needed for unpiloted vehicles.
- ❑Such algorithms can also provide assistance or recommendations for piloted aircraft.

Image courtesy of Wikipedia

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Commercial Aircraft requiring gliding since 2010

Date	Flight	Aircraft	Location	Cause	Result	Total fatalities	Occupants
22 May 2020	Pakistan International Airlines Flight 8303	Airbus A320-214	Model Colony, Karachi	Dual engine failure after belly landing and go-around, loss of engine oil	Crashed into buildings on approach, 97 on board were killed and one person on the ground was also killed.[18]	98	99
15 August 2019	Ural Airlines Flight 178	Airbus A321	Near Zhukovsky International Airport, Moscow, Russia	Complete dual engine failure due to bird strikes	Occurred moments after takeoff from Zhukovsky International Airport. Aircraft glided & successfully landed in corn field.	0	233
28 November 2016	LaMia Flight 2933	Avro RJ85	Near Medellín, Colombia	Fuel exhaustion	Took off with insufficient fuel reserves, crashed about 10 nmi (19 km) short of destination after short holding delay.	71	77
4 February 2015	TransAsia Airways Flight 235	ATR 72-600	Keelung River, Taipei, Taiwan	One engine autofeathered due to fault in its control module; pilots shut down wrong engine.	Crashed into Keelung River three minutes after take-off.	43	58
3 June 2012	Dana Air Flight 0992	McDonnell Douglas MD-83	Iju-Ishaga, Lagos	Dual engine failure from improper maintenance of fuel lines, failure for crew to divert to alternate airport when first engine failed	Crashed during landing approach into densely populated neighborhood. All 153 on board were killed and an additional six on the ground were killed.[17]	159	153
13 October 2011	Airlines PNG Flight 1600	De Havilland Canada Dash 8-103	Near Madang, Papua New Guinea	Pilot selected beta (ground braking) prop mode in flight, props oversped, engines failed	Pilots attempted an off-airport forced landing; aircraft struck trees and caught fire. Pilots, flight attendant, and one passenger survived with injuries.[16]	28	32

Image courtesy of Wikipedia

[1] Atkins, Ella. "Emergency Landing Automation Aids: An Evaluation Inspired by US Airways Flight 1549," AIAA 2010-3381. *AIAA Infotech@Aerospace 2010*. April 2010.

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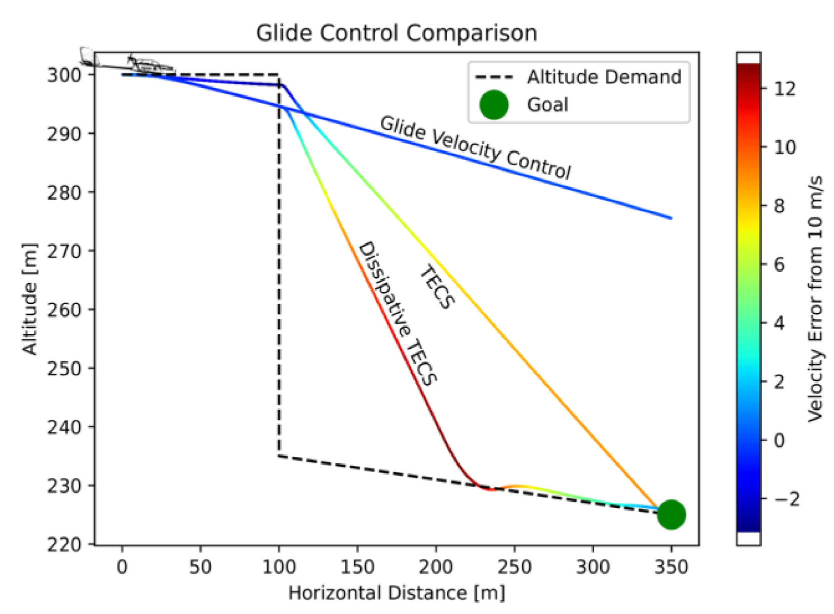
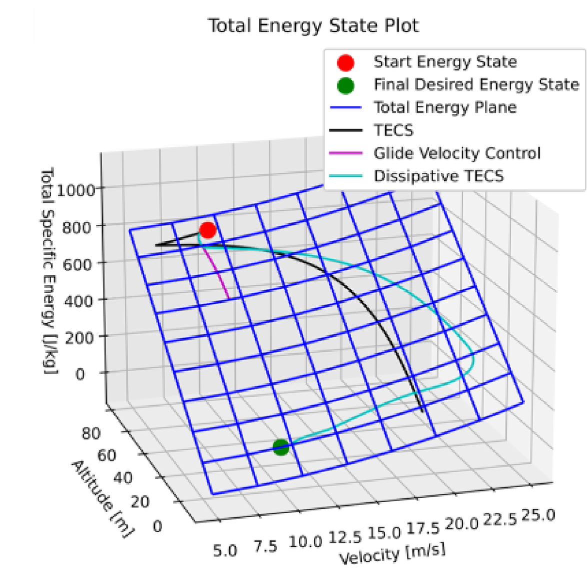
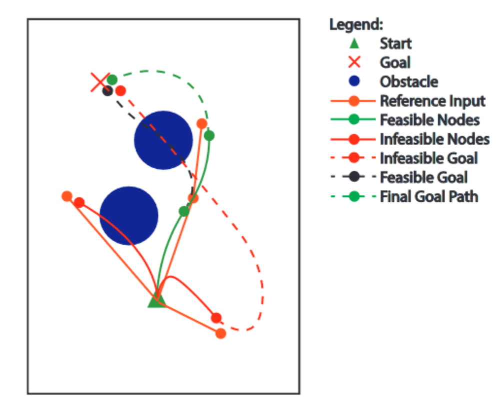
Key Contributions

- ❑**Dissipative Total Energy Control System**
- ❑Safe landing requires speeds that are neither too high or too low.
- ❑Novel approach for regulating altitude while dissipating excessive energy.
- ❑Enables a gliding aircraft to reach lower altitudes quickly.

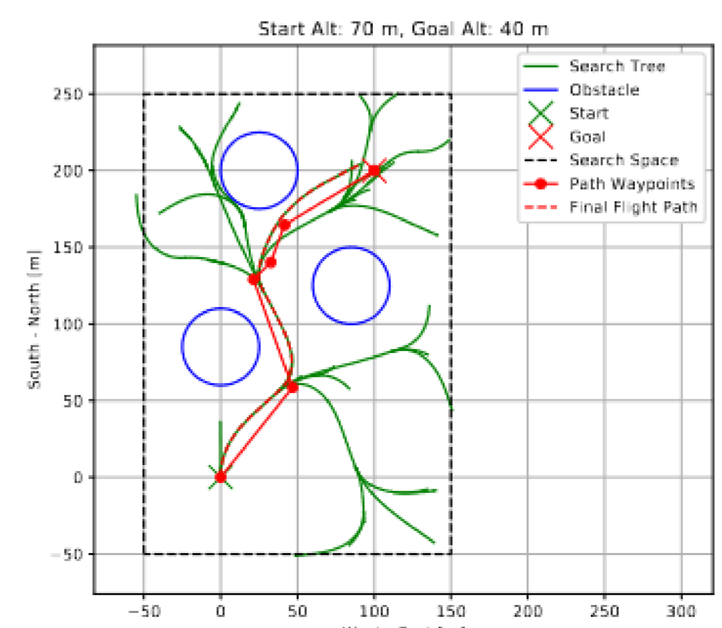




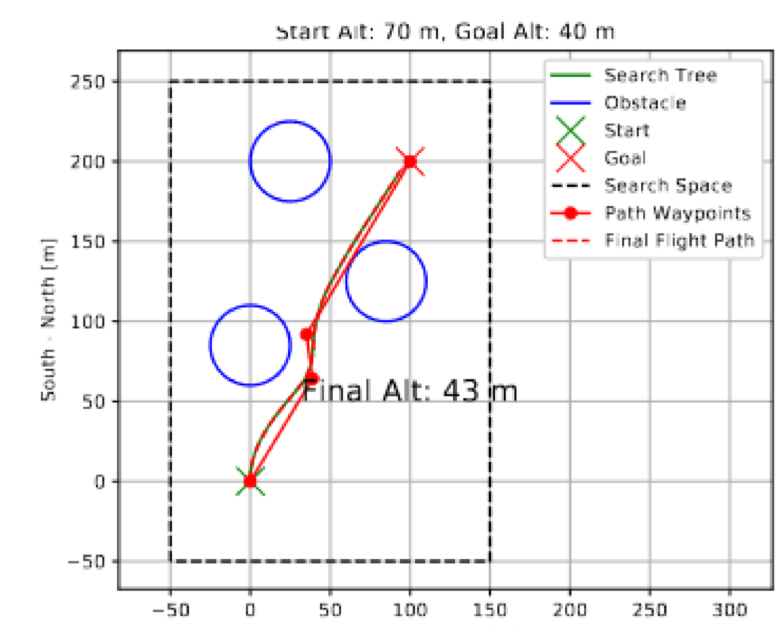
- ❑**Limited energy path cost heuristic.**
- ❑Removes nodes that do not have sufficient energy to reach goal.
- ❑Enables more efficient tree construction and faster motion planning.



Planner	Success	Avg Time [s]	Avg Samples
CL-RRT	325	6.25	742
CL-RRT Glide	1000	0.0335	12.7



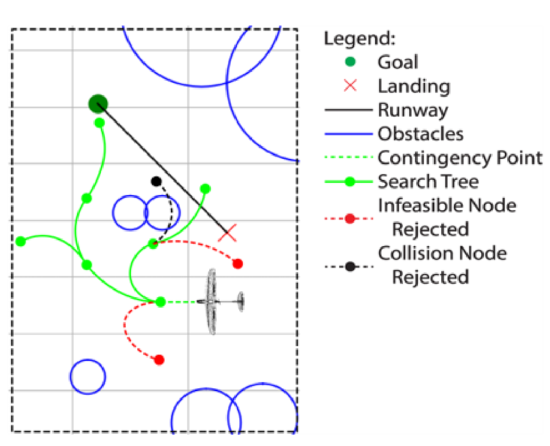
CL-RRT Algorithm (Baseline)



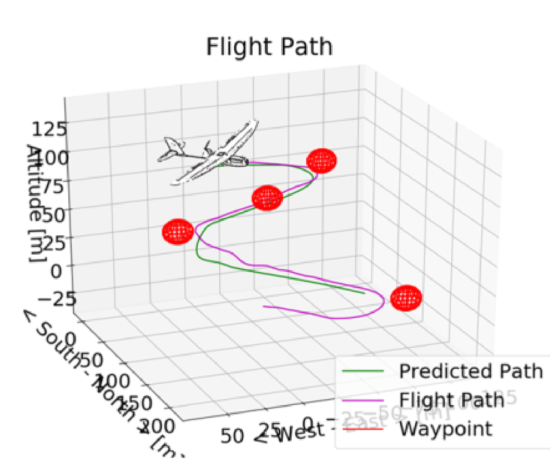
CL-RRT Glide Builds Tree More Efficiently

Technical Overview

Examine loss of thrust emergencies for fixed-wing aircraft

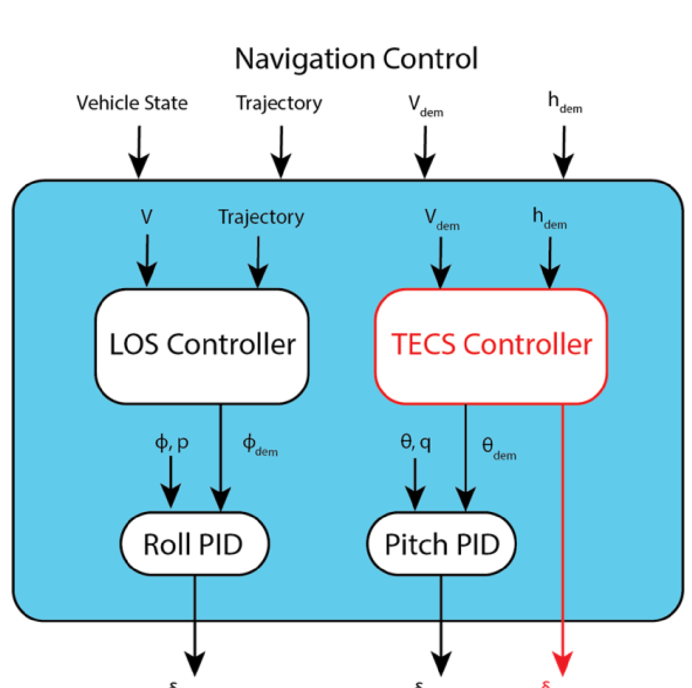


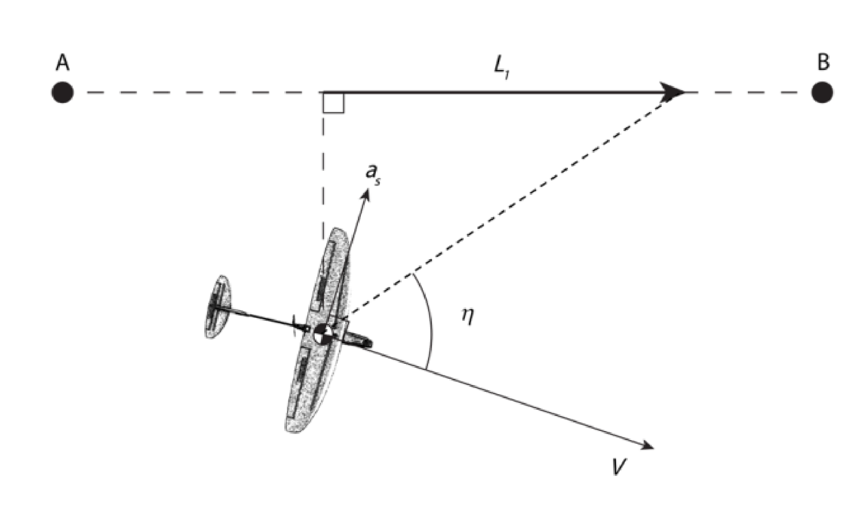
Create a sampling-based 6-DoF motion planner for rapidly computing landing trajectories



Demonstrate rapid planning and emergency landing with physical experiments

- ❑Emergency power-out landing has several key needs described below.
- ❑Ability to consider aircraft energy.
- ❑Capacity to account for nonlinear aerodynamics.
- ❑Incorporate no-go zones to maximize safety of those on the ground.
- ❑Rapid (~s) generation of trajectories.
- ❑Our approach incorporates CL-RRT, which is a sampling based planner that forward simulates through the control systems and the vehicle dynamics to build a tree from the start to the goal [2].
- ❑We use two different types of path-following controllers.
  - ❑Line of Sight Controller for lateral plane
  - ❑Total Energy Control System (TECS) for longitudinal plane.





$L_1 = \frac{1}{\pi} BTV, \quad a_s = \frac{4B^2V^2\sin(\eta)}{L_1}, \quad \phi_{dem} = \cos(\theta)\arctan\left(\frac{a_s}{g}\right)$

[2] Kuwata, Yoshiaki, Justin Teo, Gaston Fiore, Sertac Karaman, Emilio Frazzoli, and Jonathan P. How. "Real-time motion planning with applications to autonomous urban driving." *IEEE Transactions on control systems technology* 17, no. 5 (2009): 1105-1118.

Experimental Results

- ❑The autonomous emergency landing algorithm was implemented on a small fixed-wing radio-controlled aircraft.
- ❑The algorithm was evaluated using the following protocol.
  - ❑ Aircraft is piloted to desired altitude and then put into autonomous waypoint mode.
  - ❑ Propeller is turned off to create a loss-of-thrust event.
  - ❑ Emergency landing planner is activated and uses a pre-loaded map featuring no-fly-zones and a runway.
  - ❑ Aircraft flies to the next way-point to give the planner enough time to find a path.
  - ❑ Once a feasible landing plan is found, the plan is executed from the current way-point.
  - ❑ Aircraft autonomously flies the new trajectory and lands at simulated runway.
- ❑Experiment process was repeated three times to illustrate consistency of our approach.
- ❑Flights were performed under ideal outdoor conditions.

Attribute	Value
Wingspan	877 mm
Length	688 mm
Mass	270 grams