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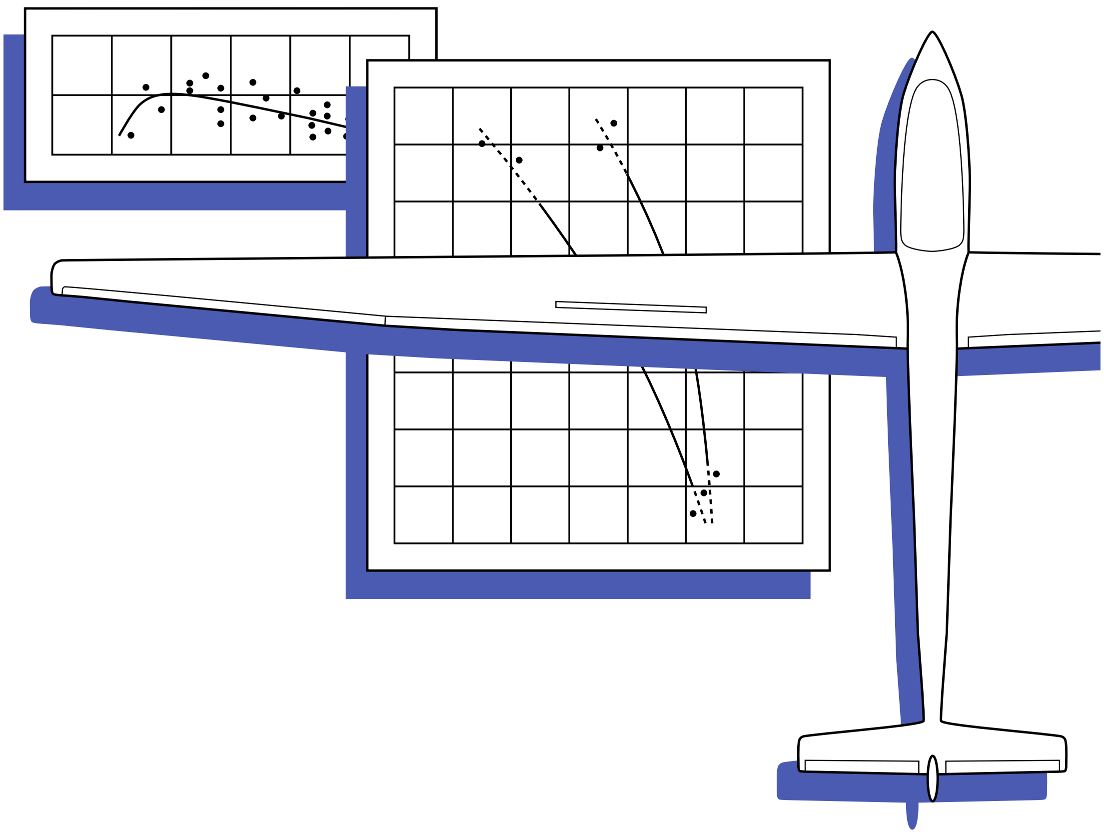

- **A hierarchical task analysis of glider aerotow operations**

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Technical Soaring

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From the Editor

Publication Date

This issue is the third of Volume 46 of *TS*, corresponding to July-August 2022. For the record, the issue was published in June, 2024.

About this issue

The article in this issue of *TS* examines systematically the numerous steps or tasks involved in the aerotowing operation to launch a glider. Readers may remark that the previous issue of *TS* also looked at aerotowing, however from a very different perspective, covering the historical first steps in aerotowing a century ago. The article in the present issue on the other hand essentially answers the question of who does what in aerotowing through a comprehensive hierarchical task analysis. This structured understanding of aerotowing operations will hopefully contribute to improving flight training and safety and may help innovators to introduce some automated tasks for the next century of aerotowing.

Very Respectfully,

Kurt Sermeus
Editor-in-Chief, *Technical Soaring*
`ts-editor@ostiv.org`

Working both ends of the tow rope: A hierarchical task analysis of glider aerotow operations

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Abstract

This research addresses the question "who does what?" in contemporary aerotow operations. This question is answered using a qualitative approach called the hierarchical task analysis, where results are presented in comprehensively branched graphical form. For this, 123 tasks along with the stakeholders performing them are identified. Additionally, 23 prerequisites for tasks to be performed and relationships between these artifacts are determined. Results are intended to inform automation design for aerotowing in future research. Validity of the results is increased by involving a panel of subject matter experts on the topics of aerotowing, flight control and aircraft design. To the best of the authors' knowledge this results in the first comprehensive overview of aerotowing tasks that is suitable for informing automation design.

Acronyms

ATC air traffic control

HTA hierarchical task analysis

IMC instrument meteorological conditions

NORDO no radio communication

SBO sport gliding operating procedures (German: Segelflugsport-Betriebs-Ordnung)

SME subject matter expert

VFR visual flight rules

Introduction

Aerotowing is one among multiple ways of launching gliders. While it offers some benefits compared to other methods, mainly operational flexibility, it does so at a cost in terms of pollution and noise emissions. One potential way to alleviate this environmental impact is to automate some aerotow-related activities. By reducing the impact of human variation, noise may be emitted over less sensitive areas and more optimal trajectories, requiring less energy, may be followed. Generally, automation has the potential to reduce the workload of the flight crew as well as the tracking error along a given flight path [1, chapter 11]. However, before automating aerotow-related tasks, we need to understand what tasks are currently performed by the humans involved. Only then can we identify tasks suitable for automation.

This article was peer reviewed by two independent, anonymous reviewers.

State of the Art

The question of "Who does what?" is one that is frequently asked in flight deck design. To answer it, task analyses are common tools.

Goal-oriented task analyses [2] feature a four-level hierarchy from goal to sub-goal to task and sub-task. The strict hierarchy has its benefits for designing cockpit systems with the intent of improving flight crew situation awareness. In the gliding context, Michel and Klingauf [3] performed a goal-oriented task analysis which includes an in-depth analysis of aerotow-related tasks. However, this work is restricted to tasks falling under the responsibility of the glider flight crew. Tasks performed by other parties – such as ground crew members or the towplane flight crew – were excluded by Michel and Klingauf.

Compared to goal-oriented task analyses, hierarchical task analyses are less stringent in terms of levels of hierarchy [4]. This leniency makes them particularly suited for identifying automatable tasks instead of flight deck interfaces [5].

Method

The research at hand identifies human-performed aerotow-related tasks using the traditional "clean sheet" hierarchical task analysis (HTA). With this heuristic method, a subject matter expert (SME) initially identifies tasks and their preconditions before decomposing them to further sub-tasks. Sub-tasks are recursively decomposed until the results are sufficiently granular for the HTA's objective. Results are documented in a tree-diagram showing the relationships of tasks, preconditions and sub-tasks. Traditionally, HTAs also involve a panel of SMEs for validating the initial proposal, confirming correctness and adequate coverage of the objective.

Stanton's [6] guidance defined the steps of the HTA as follows:

Objective of analysis

Before the core part of the analysis commences, the objectives must be captured. This will drive the level of detail that must be present in the results. For the research at hand, the objective of the HTA is defined as providing an overview of tasks and participants for conventional aerotow operations. The level of detail should be sufficient so that tasks lending themselves to future automation can be identified and that can then inform control function design.

Scope of analysis

Any HTA will come across content that is outside of the scope of the analysis. Clearly identifying these boundaries and limitations will help focus effort on the objective. In case of the research at hand, the following aerotow-related aspects are excluded from the HTA.

Automated tasks Conventional aerotow operations with gliders are mostly manual tasks that contain no automation. However, the flight crew members may still be supported in their tasks by supporting systems, such as angle of attack monitors / indicators and traffic alerting systems.

Retractable-gear towplanes The vast majority of towplanes is equipped with fixed landing gears. The effort of finding literature and SMEs for operating retractable-gear towplanes provides little additional benefit to the HTA's objective.

Operations requiring ATC clearance The vast majority of tow operations is conducted per visual flight rules (VFR) in airspace where no air traffic control (ATC) clearance is required. Tasks requiring coordination with ATC are therefore seldom performed and provide little additional benefit to the analysis. Further supporting the exclusion of operations requiring ATC clearance is the fact that ATC may sometimes issue "blanket clearances" in the form of gliding sectors or wave windows to glider operations. Such blanket clearances require minimal in-flight coordination with ATC and therefore have no practical differences to operations outside of airspaces requiring ATC clearance.

Operations in IMC While some jurisdictions enable gliding operations in instrument meteorological conditions (IMC), these are seldom performed and are of no practical relevance.

NORDO operations Operations with no radio communication (NORDO) are infrequently performed. While signaling frameworks, such as the American soaring signals [7], allow rudimentary communication and negotiation between towplane and glider flight crews, more complex negotiations almost always require radio telephony. Even for aircraft not equipped with permanently installed radio telephones, hand-held devices are easily available to allow such verbal communications.

Multi-glider tow operations While subject to some flight training curricula [8, section 1.8.2.1] and operating procedures [9, section 2.3], simultaneously towing multiple gliders with one towplane is rarely performed. For the majority of operations capturing the coordination necessary for multi-glider tows provides no benefit.

Cross-country aerotows Cross-country aerotows are occasionally performed to relocate a glider to another airfield or for aero-retrieving a glider after landing out. During regular aerotows the main objective is to provide the glider with sufficient potential energy at a suitable location for extended free flight. Therefore, they mainly feature climbing segments with sporadic horizontal flight segments. Cross-country aerotows, however, are characterized by their extended horizontal cruise segments and may even contain descending segments of the towplane-glider-combination. Since these operations again form a minority of overall aerotows, they are excluded from further analysis.

Failure of tow rope release mechanisms The release mechanisms that connect the tow rope - to both the towplane and the glider - are usually simple mechanical or electromechanical devices. Since they are installed on the respective airframes, they are subject to continued airworthiness inspections and failures of these mechanisms are exceedingly rare. Therefore, the emergency procedures associated with failures of the release mechanisms are excluded from the HTA.

Aerotow landings Aerotow landings are usually performed for the purposes of advanced flight training or as an emergency procedure in case of simultaneous failures of both tow rope release mechanisms in the towplane-glider-combination. Since failures of the tow rope release mechanisms are excluded from the HTA, the preconditions necessitating an aerotow landing are not given. Therefore, tasks associated with aerotow landings can be safely excluded from the HTA without affecting its validity.

Daily pre-flight, daily post-flight and irregular ground-based activities The aerotow operations that are subject to this analysis are embedded in a multi-sortie tow operation. As such, daily pre-flight activities (such as selecting proper equipment, performing pre-flight inspections and functional checks of equipment and aircraft), daily post-flight activities (such as cleaning and stowing the equipment and aircraft) as well as irregular ground-based activities (such as refueling the towplane) are excluded from further analysis.

Another assumption in the analysis is that aerotows are performed per the standardized sport gliding operating procedures (SBO) issued by the German Aeroclub [9]. While local procedures may vary inside the SBO's jurisdiction and abroad, the SBO may be seen as a set of best practices that is frequently adhered to for all practical purposes.

Literature-driven decomposition of tasks

Once the objective and scope of the HTA were defined, aerotow-related tasks were identified. Operating procedures [9], glider pilot flight training literature [8, 10–20], tow pilot training literature [21–25] and EASA regulatory guidance AMC1 FCL.805 [26] and AMC1 SFCL.205 [27] were reviewed for task descriptions. These descriptions were sorted and tasks were continued to be decomposed into associated sub-tasks based on the literature description. Sub-tasks were then iteratively decomposed into further sub-tasks until sufficient task granularity was reached to satisfy the HTA's objective. Where preconditions for executing tasks exist, these were captured as well. Then, for the bottom-most sub-tasks in each branch, the party responsible for performing the task during the aerotow was identified.

Contrary to the recommendations of Stanton [6], no comprehensive textual description of each task or sub-task was captured. Instead, the ensuing review by SMEs ensured that the task's title was sufficiently concise and non-ambiguous to allow readers familiar with aerotow operations to understand the scope of the task.

Even though Huddlestone et al. [5] point out that traditional HTAs quickly become bloated and cumbersome to use when planning tasks are addressed, the aerotow HTA also models planning tasks. This was thought appropriate since trajectory planning tasks can often-times be automated by using ground-based or airborne software components. This, in turn, may reveal tasks suited for automating aerotows that would have remained hidden if the concerns of Huddlestone et al. would have been heeded to.

Review by subject matter experts

The hierarchy of tasks and their allocation to the parties performing them was presented to a panel of SMEs. The qualification of each SME is listed in Table 1. Before commencing the review, the SMEs were trained on the procedures associated with HTAs. As part of their training, they were instructed to address the following objectives during their review:

Correctness The tasks captured are actually performed during aerotow operations. The relationship between sub-tasks and the tasks actually exists. The correct preconditions necessary for executing the tasks are captured.

Practical completeness All relevant tasks are captured.

Understandability The terminology in the task title is non-ambiguous and conveys the scope of the individual task or sub-task to readers with an aerotowing background.

Granularity The level of detail to which tasks are decomposed to is sufficient to satisfy the overall objective of the HTA.

When any SME noted a potential deviation from the objectives, the respective deficiency was discussed within the panel. Corrective action was performed on the HTA until a consensus between all SMEs was reached.

Table 1: Qualification of SMEs

SME	Qualification
SME #1	glider flight instructor with 300+ aerotows as glider pilot; accredited human factors specialist; research pilot in university flight department; research background in flight mechanics and human factors
SME #2	pilot for remotely piloted research aircraft; research background in flight mechanics and flight control
SME #3	tow pilot with ≈ 500 aerotows in towplanes of multiple categories; tow pilot for aerotow flight test campaign of the Akaflieg Stuttgart's fs35 towplane; glider flight instructor with ≈ 400 aerotows as glider pilot
SME #4	research background in aircraft design and operation
SME #5	tow pilot with 1000+ aerotows in towplanes; class rating instructor with privileges to instruct tow pilots; glider flight instructor with 1000+ aerotows as glider pilot; glider pilot during world's first electric aerotow with Extra 330 LE; research pilot in university flight department and in a mountain wave project

Results

The core results of the HTA is a tree of tasks, preconditions and sub-tasks presented in graphical form (see Fig. 1 and Fig. 2, including sub-figures).

Figure 1 shows that aerotowing tasks can be decomposed into two main categories. The first category consists of tasks that are unspecific to this type of operation. These include the activity of hand-flying the glider or towplane ("aviating"), navigating, communicating and operating aircraft systems. These generic flying duties are the responsibility of the respective aircraft's flight crew. In gliding operations landing times for each aircraft operating at the airfield are also captured, irrespective of the method of launch. Ground crews may support the flight crews in capturing these times.

The second main category of aerotowing tasks in Fig. 1 consists of a series of specific activities: planning of the aerotow takes place, the towplane-glider-combination is staged, take-off and initial climb are performed, and a main climb phase is conducted before the tow is terminated and the towplane returns to the airfield. For each of these aerotow-specific tasks, Fig. 2 illustrates a detailed decomposition into sub-tasks, along with who is responsible for performing them and what conditions must be met for them to be performed.

At the current level of granularity a total of 123 tasks and sub-tasks were identified as being relevant for aerotowing a glider. 23 conditions were identified as being the prerequisite for one or more sub-tasks. By far the most frequent condition that influenced whether a sub-task was performed or not was the tow rope configuration. Normal and abnormal procedures performed by the towplane flight crew or ground crew vary with whether a conventional or retractable tow rope is used. Additionally, the actions accommodating a premature termination of the aerotow while the towplane is still performing its ground take-off run depend on the performance observed and the obstacle situation in the departure sector. Responsibility for performing the many tasks is distributed between the towplane flight crew, the glider flight crew, the ground crew as well as the operations officer[1] .

The presented results have some limitations that are inherent to the method of the HTA. These limitations are presented and discussed in the Appendix.

Conclusions

The results of the HTA provide a structured overview of tasks performed during conventional aerotow operations and who is responsible for performing them. This overview of contemporary operations is suited for informing automation design and systems design for aerotow automation projects. While it is now possible to identify automatable tasks, more detailed design activities - such as formulating mathematical optimization and control problems - still require intermediate steps.

Before an automation task candidate can be automated, it will be necessary to determine (a) whether automation should rather emulate the task's human behavior or other behavior is more desirable, (b) the parameters that can influence the task's outcome, and (c) how an adequate subset of these parameters can be processed by automation.

Future work

Even with the limitations listed in the Appendix, the HTA's results have already been successfully used to identify the functions necessary for an aerotow-capable automated flight control system as part of the *Safe and quiet flights through high levels of automation and electric propulsion demonstrated by electric aerotowing*[2] research project. There, they have been combined with quantitative methods for enabling functional hazard assessments as part of systems engineering activities [28]. Future work needing a more granular description of aerotow-related tasks is free to expand on the current HTA.

However, the aerotow HTA's results are not restricted to automation design. They may be used to crosscheck contemporary flight training curricula for completeness. For designing non-automated support systems for aerotow operations in the frame of future work, it might also be beneficial to remodel the aerotow HTA into a goal-oriented task analysis and use it to extend the work of Michel and Klingauf [3].

Acknowledgements

The work presented in this paper has been performed as part of the "Safe and quiet flights through high levels of automation and electric propulsion demonstrated by electric aerotowing" project (with the German acronym SiFlA). This research was supported by the German national aviation research program (LuFo) funded by the German Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag. The authors thankfully acknowledge this support.

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[1]Different terms are used to describe the person performing this function. In Canada, the term "flight line manager" is used instead. In any case, the term "operations officer" describes the person that coordinates the launching and recovery of gliders within the overall flight operations at the airfield.

[2]SiFlA (German: "Sicher und leise Fliegen durch hohen Automatisierungsgrad und elektrische Antriebe am Beispiel des e-Schlepps")

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Appendix
Limitations of the HTA

The results of the present research have some limitations that are inherent to the method of the HTA. These limitations include the following aspects:

Formal completeness HTAs will never capture all real-life sub-tasks performed for a certain overall task. Annett and Duncan explicitly caution that "*set[ting] out to make a complete description of performance [...] is to court disaster*." [4, p. 2]. Instead, iteratively decomposing tasks into sub-tasks must be aborted at some level that is practical while still complying with the overall objective. For example, in this study the task of releasing the glider end of the tow rope was not decomposed into the sub-tasks of reaching for the release knob, pulling the release knob and monitoring for proper separation of the tow rope from the glider. The SMEs have confirmed that the level of detail was sufficient for the objective of identifying tasks for automating aerotows in the future.

Qualitative approach HTAs provide a qualitative relationships between tasks and sub-tasks. As such, the presented research does not quantify aerotow-related activities, such as how much time or effort is spent on performing certain piloting tasks. Neither are tasks prioritized nor ranked.

Sequencing and parallel activities HTAs disregard sequencing of tasks or their parallel execution. For example, given the results of the aerotow HTA, it remains undefined whether planning of the aerotow sortie takes place before staging of the aircraft and whether such sequencing is even relevant. Similarly, without additional background knowledge, it is impossible to extract from the aerotow HTA that keeping the glider in position laterally and vertically behind the towplane are two distinct, yet simultaneously executed tasks.

Applicability of tasks Not all tasks will be applicable all of the time that an aerotow is being conducted. For example, some tasks may be overcome by events. One such instance may be a situation where the tow rope separates - intentionally or unintentionally - from the tow plane. In this case, tasks related dropping the tow rope or landing with an attached tow rope are simply not applicable anymore.

Experience of SMEs The available SMEs all gained the majority of their experience in European gliding operations. Due to this regional focus, procedures practiced outside of Europe may not have been fully identified. This directly relates to the issue of formal completeness above.

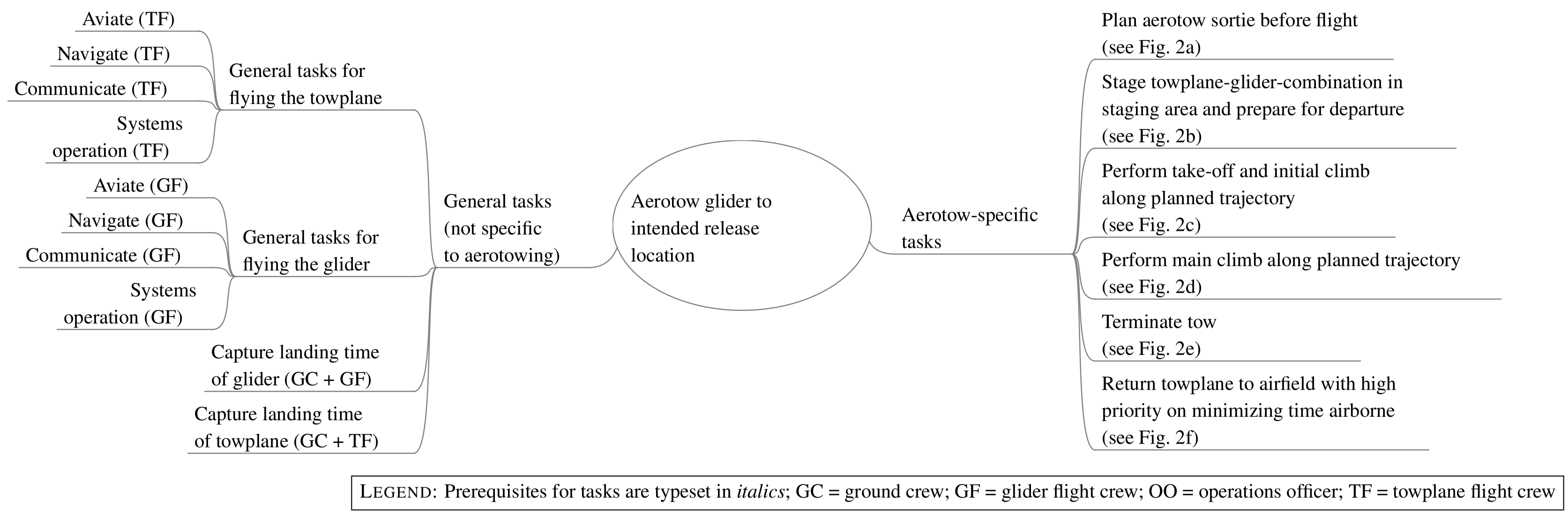
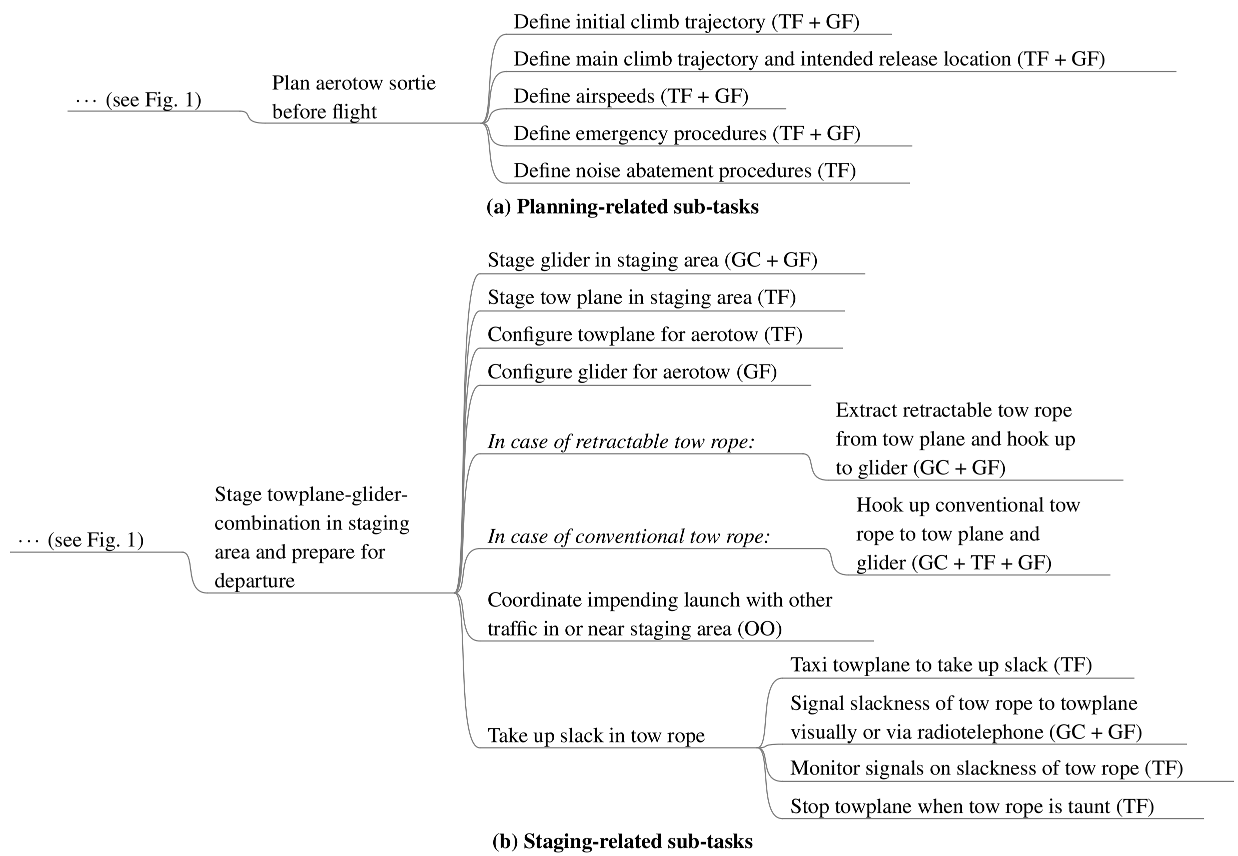
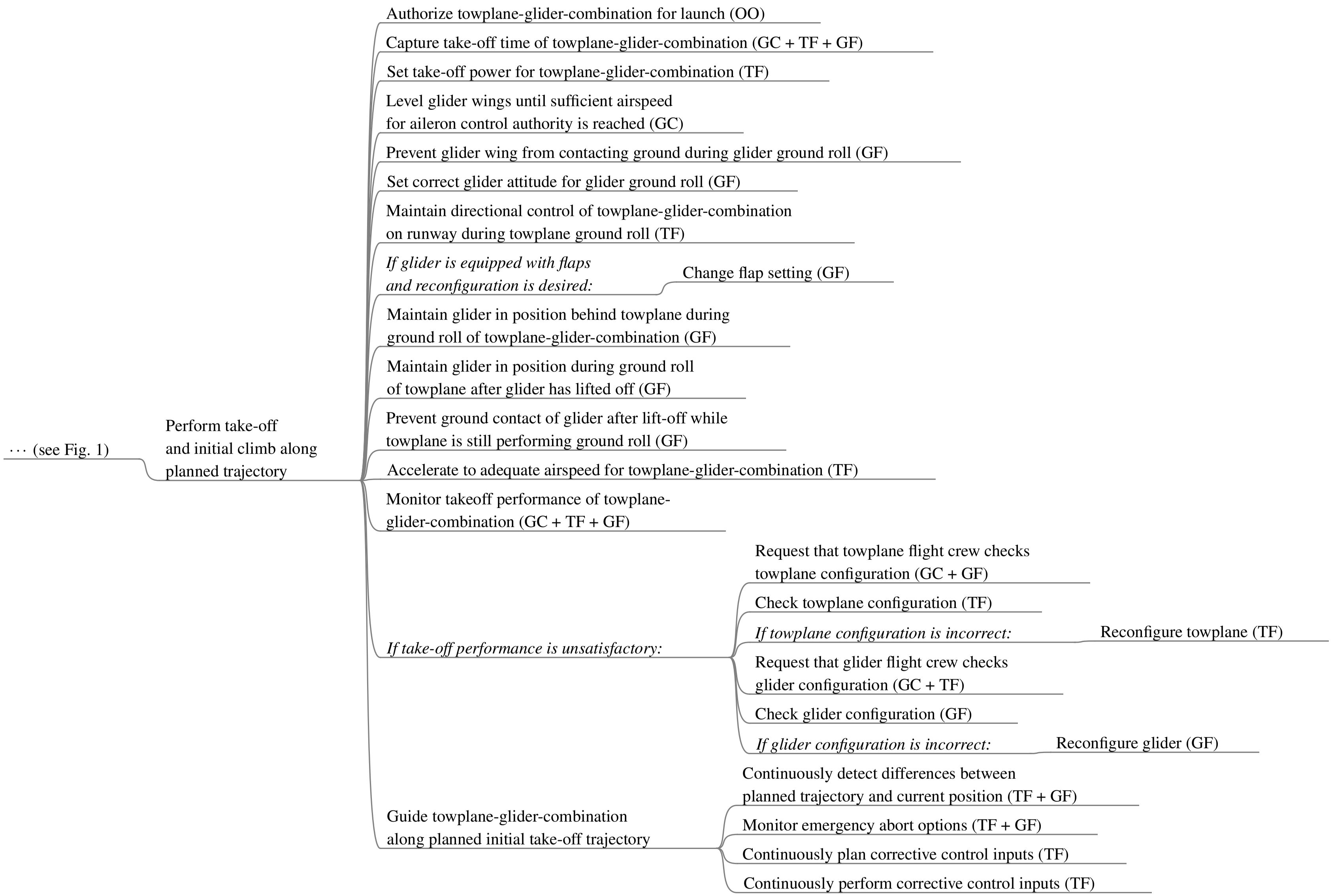


Fig. 1: Root-most tasks of aerotow HTA



LEGEND: Prerequisites for tasks are typeset in *italics*; GC = ground crew; GF = glider flight crew; OO = operations officer; TF = towplane flight crew

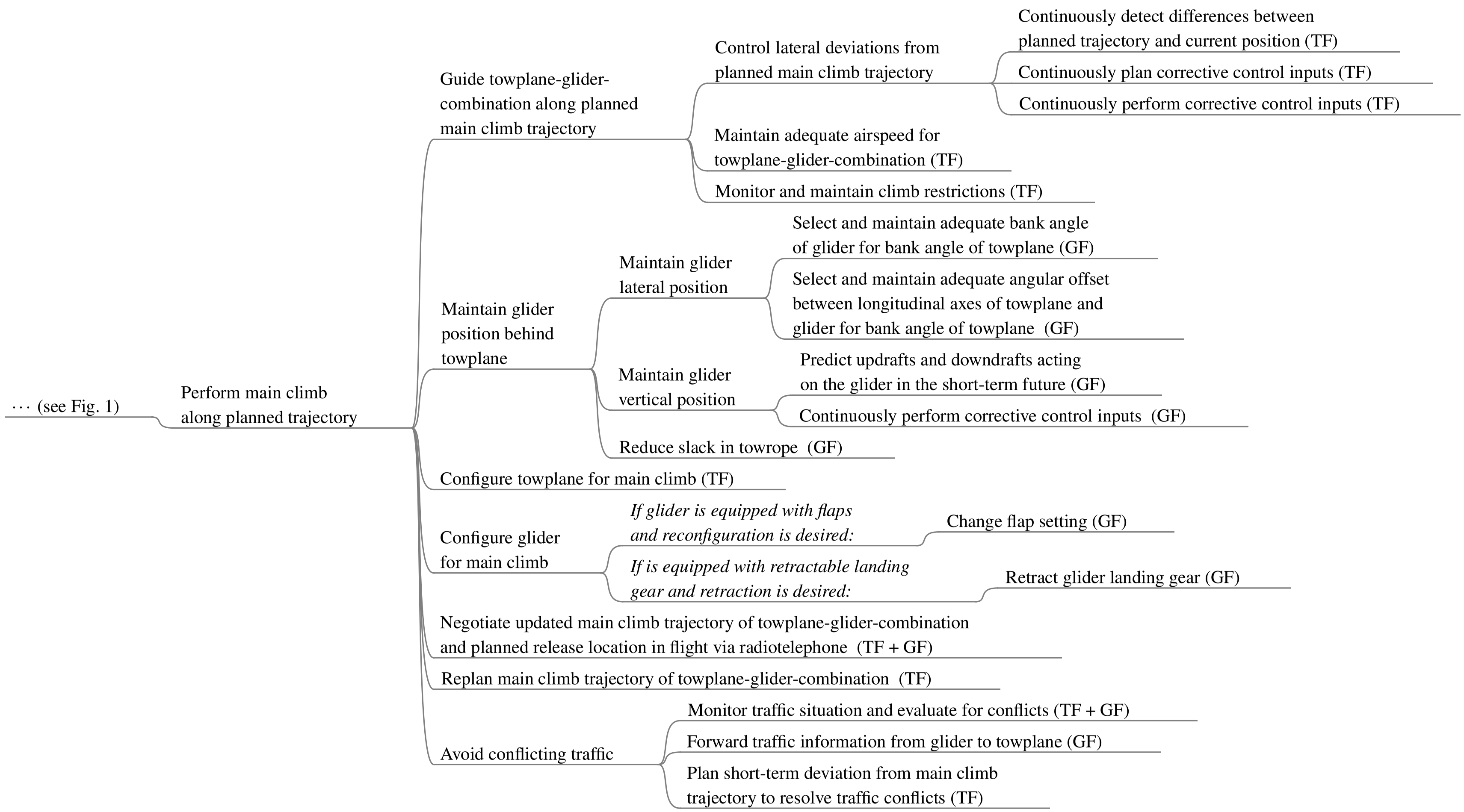
Fig. 2: Aerotow-specific tasks



(c) Take-off-related sub-tasks

LEGEND: Prerequisites for tasks are typeset in *italics*; GC = ground crew; GF = glider flight crew; OO = operations officer; TF = towplane flight crew

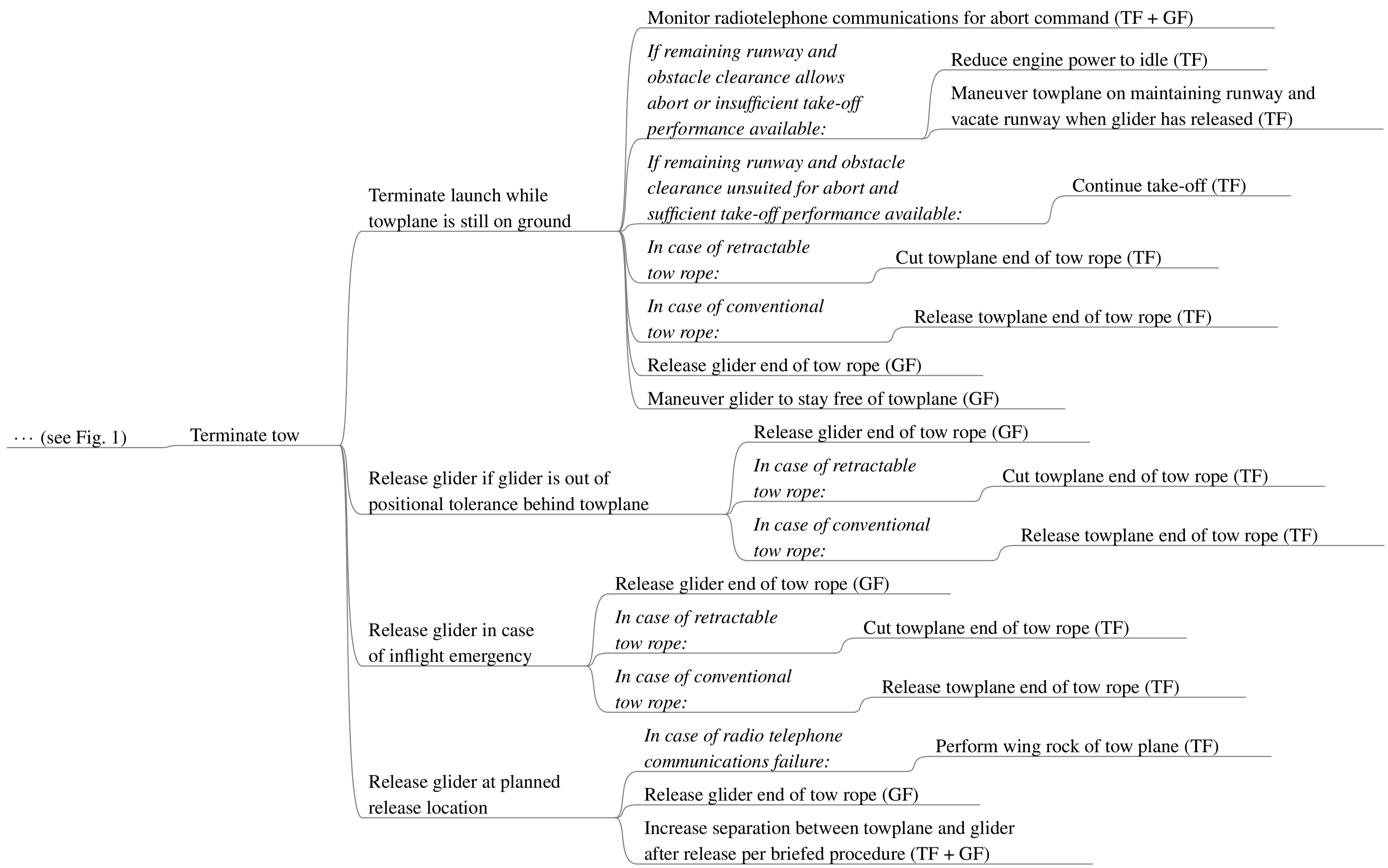
Fig. 2: Aerotow-specific tasks (cont.)



(d) Main-climb-related sub-tasks

LEGEND: Prerequisites for tasks are typeset in *italics*; GC = ground crew; GF = glider flight crew; OO = operations officer; TF = towplane flight crew

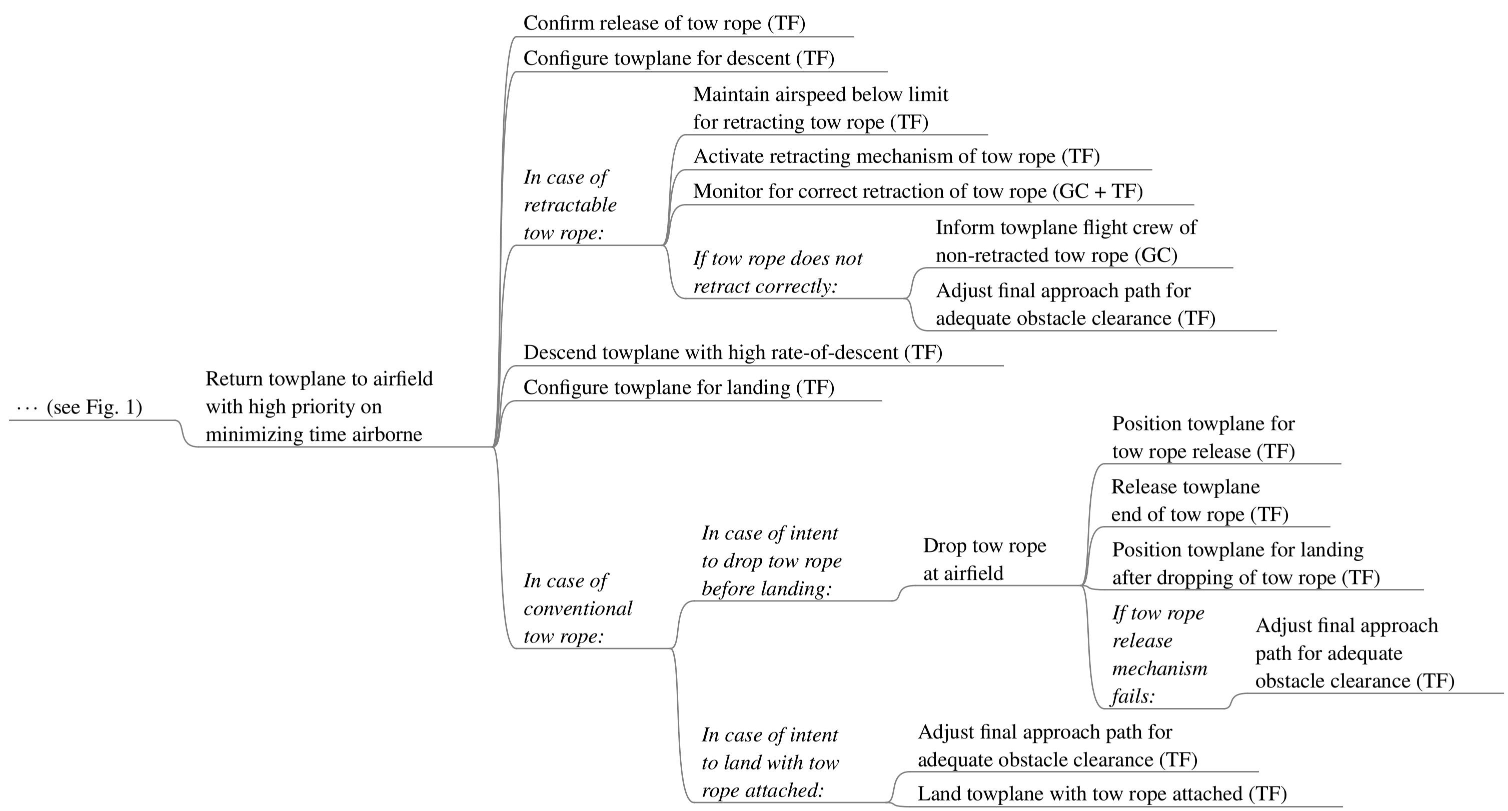
Fig. 2: Aerotow-specific tasks (cont.)



(e) End-of-tow-related sub-tasks

LEGEND: Prerequisites for tasks are typeset in *italics*; GC = ground crew; GF = glider flight crew; OO = operations officer; TF = towplane flight crew

Fig. 2: Aerotow-specific tasks (cont.)



(f) Return-to-airfield sub-tasks

LEGEND: Prerequisites for tasks are typeset in *italics*; GC = ground crew; GF = glider flight crew; OO = operations officer; TF = towplane flight crew

Fig. 2: Aerotow-specific tasks (cont.)