

A space-themed background image showing a satellite with solar panels and a bright light source in the upper right, and a spacecraft in the upper left, all orbiting a planet's horizon. The text 'A SPACE ENGINEERING ADVENTURE' is written in a stylized, spaced-out font at the top.

— A SPACE ENGINEERING ADVENTURE

ORBITAL SALVAGE

STUDY GUIDE

You fly the salvage tug **Magpie** around the planet Kestrel, catching dead spacecraft and bringing them home. Every wreck is a moving puzzle: **plan it, predict it, fly it**, then find out what really happened and why.

YOU ARE

The pilot of the Magpie

CONTRACTS

Six, about 20–45 min each

YOU WILL PRACTISE

Orbits, burns, mass and spin

FOR

Ages 12 to 16

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HOW TO USE THIS GUIDE

Read “How a contract plays” before your first flight. Before each contract, read its pages and answer the **before you play** questions, including the predictions: circle your guess on paper first. Then fly. Afterwards, answer the **after you play** questions using what the mission review showed you, and write notes in your own words.

NO SPOILERS

This guide never tells you the “right” burn, the answer to a prediction or what you will find on a wreck. The game itself tells you how your predictions went, and the review shows what happened. Finding out is the point.

WELCOME TO TARN YARD

You are the pilot of the **Magpie**, a third-hand salvage tug based at Tarn Yard. Dead spacecraft drift around the planet Kestrel: satellites that went quiet, rocket stages that never came down, a fuel pod cut loose. The Salvage Guild posts contracts to bring them home whole, or bring them down clean. You take the jobs.



The Magpie burning above Kestrel. In the distance, a tumbling observatory waits.

Nothing in orbit stays still, and nothing goes where you point it. Speeding up makes you climb; climbing makes you slower. A wreck that looks close may be on the far side of the planet in twenty minutes. That is why the game asks you to **predict before you burn**: you think about what a burn will do, fly it, and then compare your prediction with what really happened.

THE WORLD

From the game's own world notes, in the Mission journal.

KESTREL

Kestrel is a small, busy world: 600 km in radius, with oceans, deserts and a thin blanket of air. Its surface gravity is 9.81 m/s², the same pull your body knows. A craft in a low orbit at 100 km goes round once every 32 minutes and 38 seconds. Below 70 km a craft meets the air at orbital speed; a dead stage whose lowest point is below 60 km slows quickly and burns up on its first pass.

TARN AND TARN YARD

Tarn is Kestrel's rust-red moon: only 32 km in radius, orbiting 650 km up (1,250 km from Kestrel's centre) once every 78 minutes. Its gravity is so weak that its sphere of influence reaches just 62 km. Tarn Yard, the repair station where the Magpie is based, circles Tarn 48 km from its centre. Yard tenders meet incoming tows at the edge of Tarn's sphere of influence, as long as they arrive slower than 300 m/s.

THE HESPER DEBRIS FIELD

Eleven years ago the Hesper propellant depot ruptured at 205 km. About four thousand tracked fragments now fill a band between 185 and 225 km, with countless smaller ones nobody can see. Every lane-clearing contract chips away at it. Fly through the band if you must, but do not linger, and never make it worse: a cracked hull sheds new fragments.

THE SALVAGE GUILD

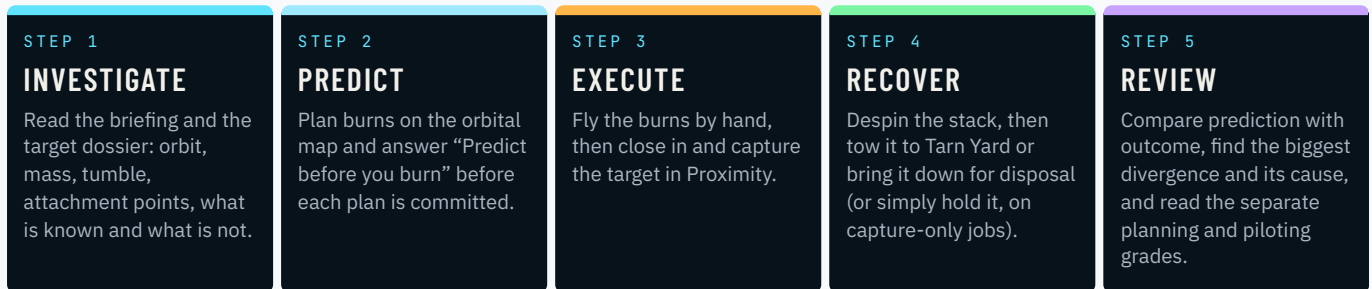
The Guild licenses salvage tugs, posts contracts and keeps the lane charts. Its rule is short: bring it home whole, or bring it down clean. Licensed crews start with capture and towing work close to Kestrel. The Expedition licence, for deep-space work beyond Tarn, is earned over years and unlocks equipment like the despin harpoon.

MAGPIE OS-7

The Magpie is a third-hand salvage tug, rebuilt by every crew that has owned her: 21.4 t dry, a Vela-2 engine, two foil-wrapped propellant tanks, sixteen RCS thrusters and a three-finger grapple on a two-joint arm. She is not fast and she is not pretty, but she has never lost a tow. Her home berth is Bay 2 at Tarn Yard.

HOW A CONTRACT PLAYS

Every contract follows the same five steps. The map's Active contract panel lights up the step you are on.



YOUR FIRST CONTRACT

A new career starts on Day 1 with 60,000 CR and the Magpie in her standard fit. The first contract, **C-009 Shakedown Run**, is **Flight School**: tutorial tips (coach marks) point at the next step on every screen. Finish it and new contracts open on the board.

Shakedown Run opens **C-011 Thrift Pod**, **C-012 Clear the Lane**, **C-014 The Silent Observatory**; The Silent Observatory opens **C-016 Inclined to Help**, **C-019 The Spinning Stage**. C-019 also needs the Heavy grapple Mk II fitted, which C-014 unlocks in the Workshop.

TIME IN THE GAME

Mission time only runs on the orbital map and in proximity ops. Menus, the journal and the workshop hold the clock.

Mission time is shown as T+ hours, minutes and seconds. Use time warp to skip long coasts: it drops back to 1× before a burn or a close approach, so you will not miss anything.

THE COLOUR LANGUAGE

Colours mean the same thing on every screen. Learn them once and the map becomes much easier to read.

 Cyan is you, the Magpie	 Amber is the target	 Dashed is a plan or prediction
 Solid is what really happens	 Green is a viable path or delivery	 Red is divergence or danger
 Violet is the moon, the normal axis, gravity		

COMPETING OBJECTIVES

Each contract has three objectives that pull against each other, shown as live bars on the map: keep the target's **integrity** high (no bumps), keep a **fuel reserve** (measured as the Δv the tug has left on its own at the end), and finish before the **deadline**. Rushing burns fuel; saving fuel takes time; going fast near a wreck risks a bump. Good salvage is a balance.

CREDITS AND KIT

A delivered contract pays credits (CR), with bonuses for things like a gentle capture or every prediction right. Credits buy equipment in the Workshop, and some contracts unlock new parts. But every tonne you add costs Δv on every mission, so choose kit for the jobs you plan to take.

THE BOARD AND THE BRIEFING

Pick a contract on the **Contracts board** to see its client, payout, deadline and whether your tug is equipped for it. Accepting it opens the **briefing**.

The screenshot shows the Orbital Salvage briefing interface. At the top, the contract is 'C-014: HALDANE INSTITUTE, TARN' with a deadline of 7 h 20 min, a payout of 48,288 CR, and credits of 212,948 CR. The central display shows a 3D model of the 'HALDANE-3' deep field observatory, a 38-tonne satellite with a primary mirror and two solar wings. The observatory is in a circular orbit at 165 km altitude, tumbling at 2.1°/s. The briefing is divided into several panels:

- Target Dossier:** Provides orbital data (165 km circular orbit, 37 min period, 6.8° inclination) and mission details (transfer window at T+08:22:51, mass of 38.0 t, tumble rate of 2.1°/s, and a 41-day adrift period).
- What We Know:** Lists known facts such as the mass, orbit, and tumble rate, and unknowns like the status of the docking port and equipment ring.
- Attachment Points:** Details three points: Docking Port A (blocked), Truss Hardpoint B (viable), and Aft Equipment Ring C (unknown).
- Competing Objectives:** Lists goals like instrument integrity (≥ 98%), fuel reserve (≥ 400 m/s), and delivery before the deadline.
- Concepts You Will Practise:** Includes orbital period, relative velocity, reference frames, angular momentum, centre of mass, rocket equation, and Hohmann transfer.
- Tug Readiness:** Shows the tug's current status, including tumble rate (2.5°/s), capture mass (40 t), and arm reach (4.4 m).

At the bottom, there is an 'Incoming Transmission' section with a message from Haldane Institute, Tarn, and a 'Contracts Board' button to accept the mission.

A briefing. Left: the target dossier and what is known and unknown. Centre: the target itself, turning, with its attachment points. Right: attachment points, competing objectives, concepts you will practise and tug readiness.

WHAT TO LOOK FOR

- **The orbit:** how high the target is compared with you, and how far ahead or behind.
- **The transfer window:** when a transfer will work, and how long until the next one if you miss it.
- **Mass and tumble:** how heavy the target is and how fast it turns (degrees per second).
- **Attachment points:** **viable** (safe to grip), **blocked** (do not grab) or **unknown** until you scan it from within 40 m.

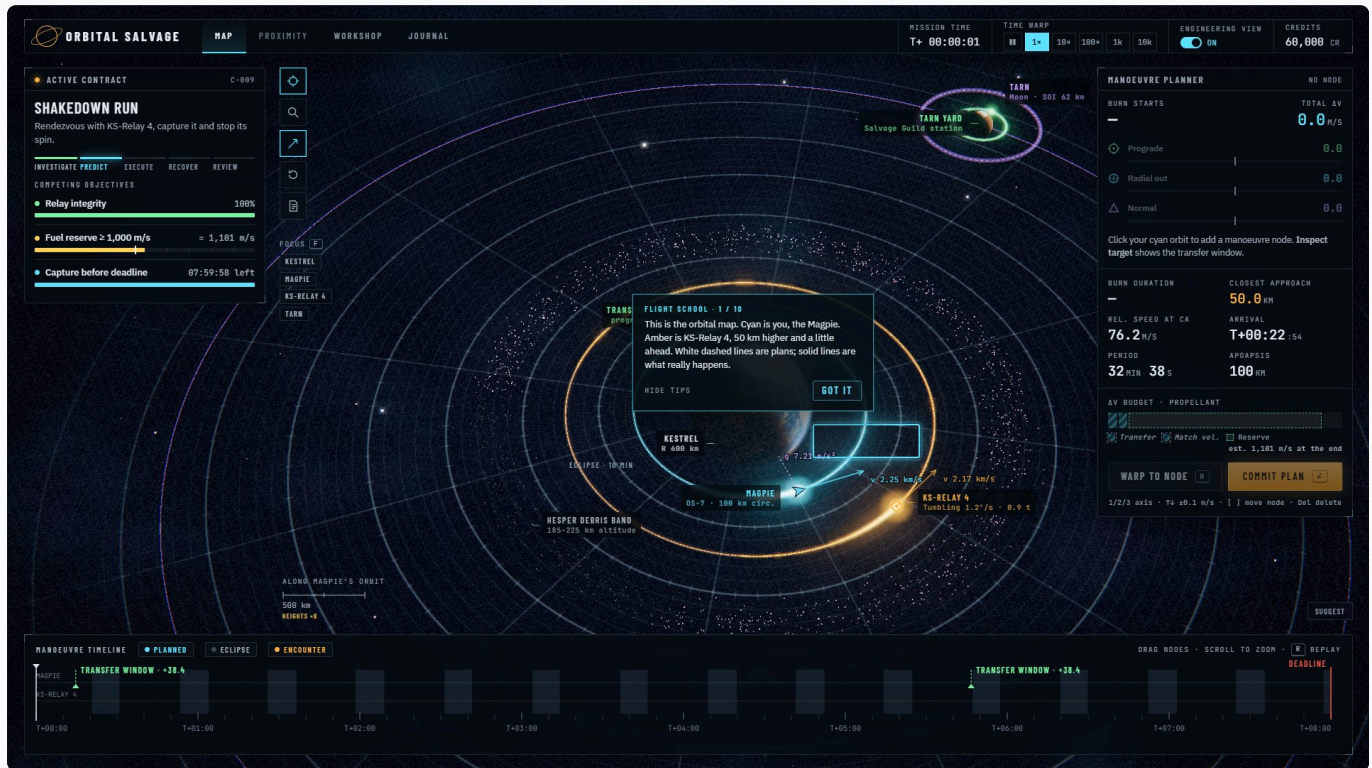
KNOWN AND UNKNOWN

The dossier separates what is **known** from what you will only find out on the job. Treat the unknowns as questions to answer during the mission, not guesses to rely on.

Incoming transmissions read the client's briefing aloud as text. When you are ready, choose **ACCEPT CONTRACT & BEGIN PLANNING** (Enter). That starts the mission clock.

PLANNING ON THE ORBITAL MAP

The map shows Kestrel from above, tilted so you can see depth. Your orbit is cyan, the target's is amber, and a plan is a white dashed path.



The map at the start of Shakedown Run, with a Flight School tip. Left: the active contract and objectives. Right: the manoeuvre planner. Bottom: the manoeuvre timeline with the transfer window marked.

MAKING A PLAN

- 1 Add a node.** Click your cyan orbit (Plan tool on) to place a manoeuvre node, a planned burn.
- 2 Set the Δv .** Drag the node's handles: prograde and retrograde (along your motion), radial in and out (towards or away from Kestrel) and normal (out of your orbital plane). Watch the dashed path change.
- 3 Time it.** Slide the node along the orbit, or nudge its time. The timeline shows the transfer window, eclipse bands and the deadline.
- 4 Read the planner.** Burn start, total Δv , burn duration, closest approach, relative speed at closest approach, arrival time, new period and apoapsis, and a Δv budget bar.

PREDICT BEFORE YOU BURN

Before you can commit a plan, a question appears: what will this burn do? There are three answers. Pick one honestly, then **COMMIT PLAN** (Enter). After the burn the game grades your answer, explains why, and awards XP. Your answers also count in your planning grade.

Each contract's pages in this guide list the questions you are likely to meet, so you can think about them before you fly.

HELPERS AND ASSISTS

ADD MATCH-VELOCITY NODE AT CLOSEST APPROACH (M) places your second burn for you. **SUGGEST** fills in a whole burn, but it is **logged as an assist** and lowers your planning grade. Try your own plan first.

FLYING A BURN

You fly every burn by hand. The skill is starting on time and stopping on the line.

- 1 **Warp to the node.** Press **B**. Time warp stops just before the burn (10 seconds before, or 30 in Flight School) and drops to 1×.
- 2 **Watch the gauge arm.** A standby gauge counts down to ignition. In Flight School the clock then waits for you.
- 3 **Hold Space to fire.** The needle shows the Δv you have flown against the planned line. A live line shows the encounter or orbit you will get if you cut now.
- 4 **Finish gently.** The last 0.5 m/s is a shaded fine zone: hold **Shift** as well for 10 % throttle. Release **Space** to cut.

LATE, LONG AND OFF COURSE

- From one second late the gauge says how late you are; from three seconds it turns red: fire now.
- A burn held too long (an **overrun**) or cut short changes where you meet the target. A few tenths of a metre per second can move the encounter by hundreds of metres.
- If a burn leaves you off course, the planner says so and offers **ADD CORRECTION NODE**. Correct first, then match velocity.

ARRIVING

- On a transfer you arrive at **closest approach**. The match-velocity burn removes the difference between your velocity and the target's, so it seems to hang beside you.
- Within 5 km, matched and staying close, the map offers **Proximity**: press **P**.
- If you are drifting apart instead, the map tells you to plan a correction first.

BURN ASSIST

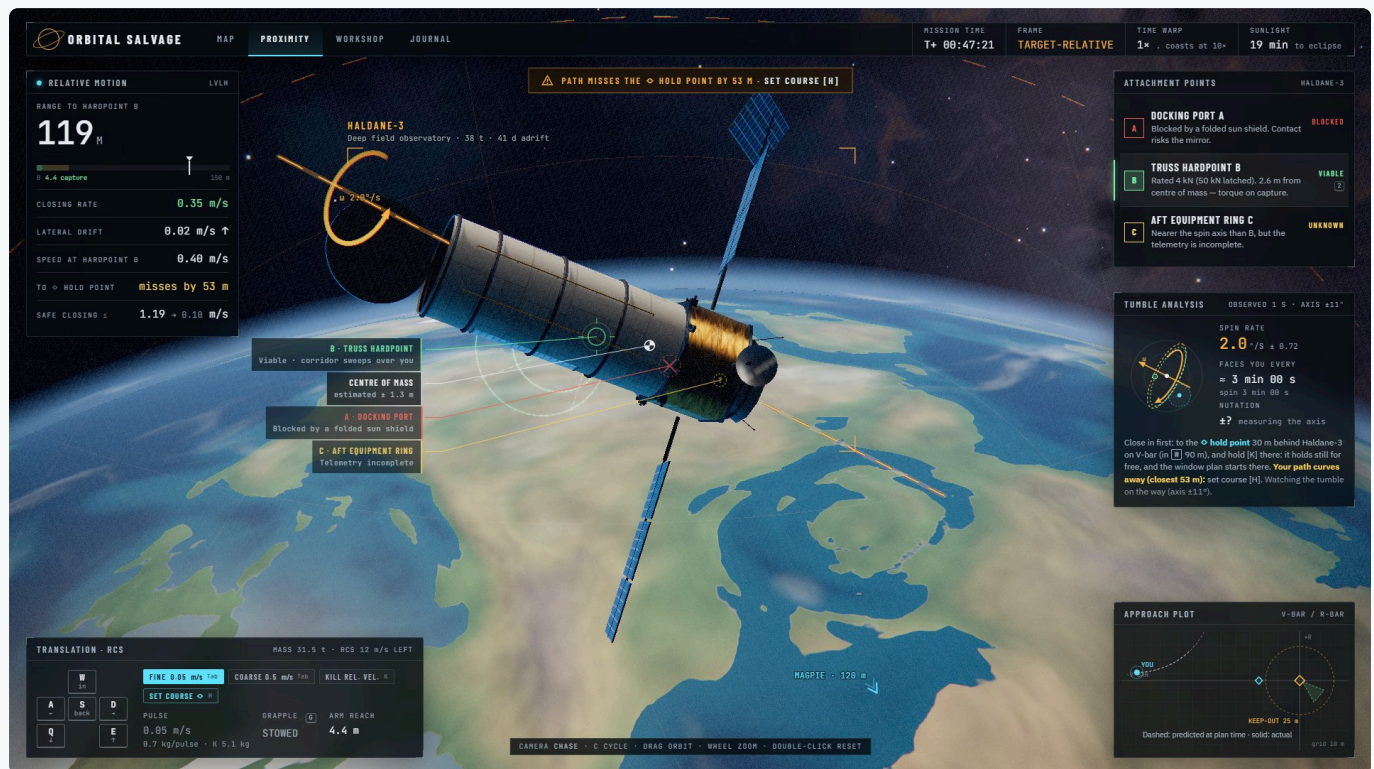
In Settings, **Burn assist** cuts each burn automatically at its planned Δv . It helps if holding a key is hard for you. Assisted burns are not scored for piloting; your planning and predictions still are.

TIME WARP

The warp buttons in the top bar (or **,** and **.**) run time at 1×, 10×, 100×, 1,000× or 10,000×. Warp is limited near the target and drops automatically before burns, re-entry warnings and close approaches. Arming a burn always drops warp to 1×.

PROXIMITY: CLOSING IN AND CAPTURING

In Proximity everything is measured from the target itself, in metres and centimetres per second.



Proximity operations at an observatory. Left: relative motion (range, closing rate, drift). Right: attachment points, tumble analysis and the approach plot. Bottom left: translation thrusters (RCS).

MOVING GENTLY

- The RCS thrusters push you in small pulses: **W**/**S** towards or away from the selected point, **A**/**D** and **Q**/**E** sideways. **Tab** switches fine and coarse pulses.
- K** kills your relative velocity and holds station.
- Keep your closing speed under the **safe closing** limit: $\max(0.1, \text{range} \div 100)$ m/s. At 50 m that is 0.5 m/s; inside 10 m it is 0.1 m/s.
- A 25 m **keep-out sphere** surrounds the target. Enter it slowly, inside the approach corridor.
- A **hold point** on V-bar is a calm place to wait. **H** sets course for it (logged as an assist).

THE CAPTURE

- Scan** unknown points by staying within 40 m for a few seconds.
- The **Tumble analysis** learns the spin as you watch and counts down to the next **alignment window**, when your chosen point faces you.
- Before you grab, answer **Predict the capture**.
- Press **G** when the point is in reach and facing you, closing at 0.2 m/s or less (0.1 for full marks). If anything is wrong, the grapple refuses and says why.
- After capture the stack may still turn. Fire **despin pulses** (**F**) until it is stable, then **M** returns to the map.

BUMPS COST INTEGRITY

Touching the hull, or grabbing a blocked point, damages the target and lowers its integrity. Some targets have a sensitive instrument marked “no contact”. Slow is smooth, and smooth is fast. If the RCS runs low, **R** moves main propellant into it (crossfeed).

BRINGING IT HOME, OR BRINGING IT DOWN

What happens after the capture depends on the contract. The briefing tells you which job it is.

CAPTURE ONLY

Catch the target and stop its spin. A repair crew takes it from there. Once the stack is stable, the contract is done and you can open the review.

TOW TO TARN YARD

Plan a tow burn on the map (**PLAN TOW TO TARN** helps) that raises your orbit to Tarn's, timed so Tarn is there when you arrive. The yard's tenders meet you at the edge of Tarn's sphere of influence if you arrive slower than **300 m/s**.

With cargo attached every number changes: burns take longer and your Δv shrinks.

DISPOSAL

Burn retrograde with the wreck on the arm until its lowest point is below **60 km**, so it burns up in Kestrel's air. Then **release it** (**R** on the map) and climb so your own lowest point is back above **70 km**.

Until you climb, you share its orbit.

WHEN THINGS GO WRONG

A contract fails if the tug re-enters the atmosphere, hits Tarn, is left stranded without enough propellant, or runs out of time. You can also abandon a contract from the menu. Failure is not the end: the review still shows what happened and why, and **RETRY WITH CHANGES** lets you fly it again with what you have learned.

EVERY WRECK HAS A STORY

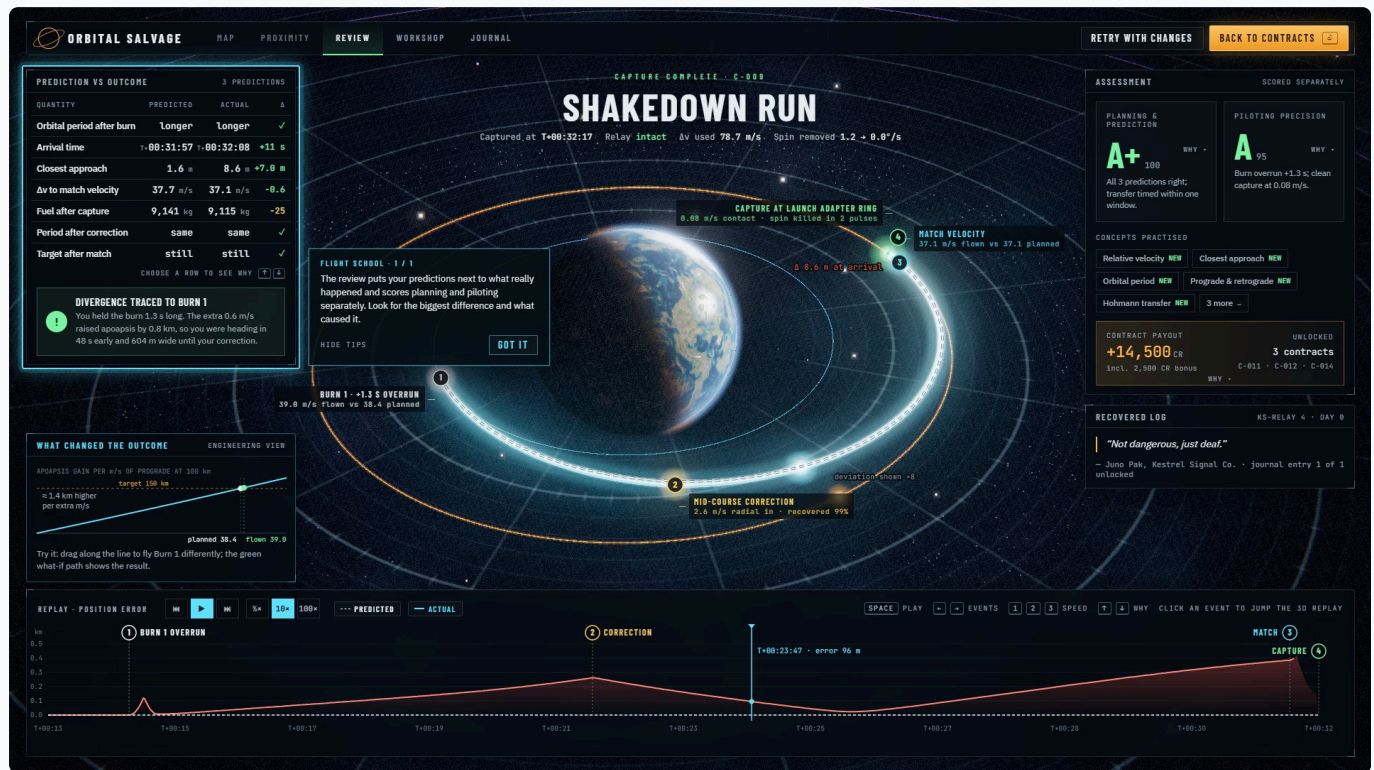
Most targets carry logs: messages from crews, controllers and flight computers. Some are released with the briefing; others are recovered when you capture the wreck, despin it or complete the contract. Read them in the **Mission journal**. They often explain why the wreck is the way it is.

THINK ABOUT IT

1. Why might a tow burn need to start earlier, relative to its planned node, than an empty burn of the same size?
2. On a disposal, why do you need to climb straight after releasing the wreck, rather than later?
3. What could make a contract fail even if every burn was flown perfectly?

THE MISSION REVIEW

The review puts your predictions next to what really happened, finds the biggest difference and explains its cause. This is where most of the learning happens.



A review after Shakedown Run. The predicted path is dashed, the flown path solid, with the difference drawn eight times larger so you can see it.

WHAT THE REVIEW SHOWS

- **Prediction vs outcome:** planned and actual values (arrival time, closest approach, Δv to match, fuel) with the difference coloured good, warning or bad, and your prediction answers.
- **Divergence traced:** the largest cause of error in one sentence, for example a burn held too long.
- **What changed the outcome:** how much one extra m/s would have moved things. Drag along the line to try a different burn.
- **Replay:** the flight again, with numbered events and a position-error chart.

TWO GRADES, NOT ONE

Planning & prediction asks: was the plan good? It counts your predictions, how well your plan aimed, how much Δv it used compared with a careful plan, and how much time you left. Each assist used lowers it.

Piloting precision asks: did you fly the plan? It counts how close each burn was to its planned Δv and time, your contact speed, clean proximity flying, the target's integrity, monoprop used and despin pulses.

Each grade is a score out of 100 shown as a letter: **A+** from 97, **A** from 92, **A-** from 88, **B+** from 84, **B** from 77, **B-** from 72, **C+** from 68, **C** from 62, **C-** from 57, **D** from 50, **F**.

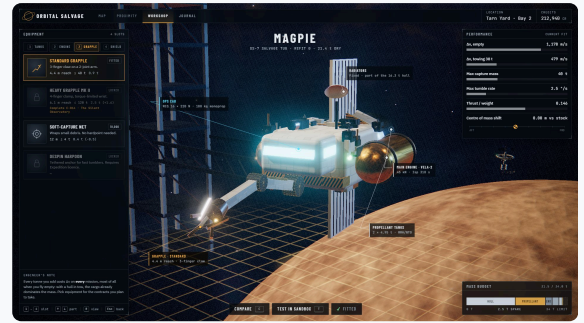
USE IT WELL

Look for the **biggest** difference first, not every small one. Ask what caused it, and what you would change. A good plan flown badly and a bad plan flown well look very different in the two grades.

WORKSHOP, JOURNAL AND SETTINGS

THE WORKSHOP

The Magpie sits in her cradle at Tarn Yard. Pick a slot (tanks, engine, grapple, shield), select a part to preview it on the tug and in the **Performance** panel (Δv empty, Δv towing 38 t, maximum capture mass, maximum tumble rate, thrust to weight, centre of mass), then buy and fit it.



The Workshop: equipment on the left, performance on the right.

PART	WHAT IT DOES	MASS	COST
Standard tanks Tanks · Fitted	2 × MLI-wrapped MMH/NT0 tanks.	2.1 t	Fitted
Extended tanks Tanks · After C-011 Thrift Pod	Stretched tanks: +1.7 t of propellant.	2.7 t	15,000 CR
Drop-in monoprop pack Tanks · In the Workshop from the start	Trades main propellant for extra RCS.	2.3 t	9,000 CR
Vela-2 Engine · Fitted	45 kN · Isp 318 s. The workhorse.	2.1 t	Fitted
Vela-2H Engine · In the Workshop from the start	68 kN · Isp 302 s. Short, punchy burns.	2.4 t	24,000 CR
Corax-3 Engine · After C-012 Clear the Lane	20 kN · Isp 365 s. Sips propellant.	2.3 t	46,000 CR
Standard grapple Grapple · Fitted	3-finger claw on a 2-joint arm.	0.9 t	Fitted
Heavy grapple Mk II Grapple · After C-014 The Silent Observatory	4-finger clamp, torque-limited wrist.	2.5 t	32,500 CR
Soft-capture net Grapple · In the Workshop from the start	Wraps small debris. No hardpoint needed.	0.4 t	18,000 CR
Despin harpoon Grapple · Requires Expedition licence	Tethered anchor for fast tumblers.	1.1 t	54,000 CR
No shield Shield · Fitted	Bare hull. Lightest option.	0 t	Fitted
Whipple shield Shield · After C-012 Clear the Lane	Spaced bumper plates. Cuts impact damage.	0.6 t	14,000 CR
Thermal blanket Shield · In the Workshop from the start	Gold MLI wrap. Light, a little padding.	0.2 t	6,000 CR

THE MISSION JOURNAL

- **Recovered logs:** the stories behind the wrecks.
- **Engineering notes:** short notes and diagrams for every concept in the game. The next part of this guide uses them.
- **Mission history:** your past contracts.

SETTINGS

Graphics quality, volumes, reduced motion, burn assist, tutorial tips (and **REPLAY TUTORIAL TIPS**), engineering view by default, and a controls reference for every screen. Settings and your career are saved on this device.

CONTROLS

Every control can be used with a keyboard; the map and Proximity also use the mouse. The same lists are in Settings → Reference.

ORBITAL MAP · PLANNING	
Click	Add a node on your orbit (Plan tool on)
Drag handle	Set the node's Δv along that axis
Drag node	Slide the node along the orbit
Tab · PgDn	Next node (Shift+Tab or PgUp: back)
1 2 3	Axis: prograde · radial · normal
↑ ↓	Nudge Δv 0.1 m/s (Shift ×10 · Alt ×0.1)
[/]	Retime the node −/+ 10 s (Shift: 60 s)
DeL / Bksp	Delete the selected node
M	Match-velocity node at closest approach
Enter	Commit the plan (after your prediction)

PROXIMITY OPS · TRANSLATE · RCS	
W / S	Forward / back along the line of sight
A / D	Left / right
Q / E	Down / up
Hold	Holding a key repeats the pulse 4× a second
Tab	Fine 0.05 / coarse 0.5 m/s pulses
K	Kill relative velocity

MENUS · MENUS & SETTINGS	
↑ / ↓	Move (W / S on the menu)
Tab	Next setting (Shift+Tab: previous)
← / →	Change a setting (Shift: fine steps)
Enter / Space	Choose
Esc	Back · on the orbital map: this menu
Click	Orbital Salvage (top bar): the menu from any screen

ORBITAL MAP · BURN	
B	Warp to the next node
Space	Hold to fire, release to cut (assist: tap)
Shift + Space	Fine throttle, 10 %
Enter	End the burn here
Esc	Cancel the armed burn

ORBITAL MAP · VIEW & TIME	
Drag · Wheel	Orbit · zoom (right-drag: pan)
F	Cycle focus (or double-click a body)
I V N	Inspect · vectors · engineering notes
R	Replay prediction · disposal: release cargo
P	Pause · proximity ops when offered
, / .	Time warp down / up
Esc	Clear the selection, then this menu

PROXIMITY OPS · CAPTURE	
1 - 9	Select an attachment point (A, B, C...)
G	Grapple the selected point
F	Despin pulse (after capture)
M	Back to the map to recover (once despun)

PROXIMITY OPS · VIEW & TIME	
Drag · Wheel	Orbit · zoom the camera
C	Camera: chase · target · LVLH
P	Pause
, / .	Time warp: ≤ 10× beyond 500 m, 1× inside
Esc	Leave for the orbital map

Safe closing speed: $\max(0.1, \text{range} \div 100)$ m/s. Capture at ≤ 0.2 m/s (≤ 0.1 for full marks). The menu: Orbital Salvage in the top bar.

READING ORBITS

An orbit is falling around a planet so fast that you keep missing it. Everything in Orbital Salvage follows from that one idea, and from a few rules about speed, height, mass and spin.

The next pages are the game's own **engineering notes**, the same ones you unlock in the Mission journal, with their diagrams. Each one ends with something to try and a list of the contracts where you will use it. You do not need to learn the formulas to play; they are there for when you want to check the game's numbers yourself.

KESTREL BY NUMBERS

600 km

Kestrel's radius

9.81 m/s²

Surface gravity

70 km

Top of the atmosphere

32 min 38 s

One lap at 100 km

2.25 km/s

Speed at 100 km

185 km–225 km

The Hesper debris band

1,250 km

Tarn, from Kestrel's centre

77 min 53 s

Tarn's orbital period

62 km

Tarn's sphere of influence

SIX IDEAS TO HOLD ON TO

1. **Speed and height are linked.** Burn forwards (prograde) and the far side of your orbit rises; burn backwards (retrograde) and it sinks.
2. **Higher is slower.** A bigger orbit takes longer to go round, so a lower craft catches up with a higher one.
3. **Timing is everything.** To meet a target you must arrive where it is, when it is there: that is the transfer window.
4. **Only the difference matters up close.** Near a wreck, what counts is your velocity compared with its velocity.
5. **Mass costs.** The same tanks give much less Δv , and longer burns, with cargo on the arm.
6. **Spin does not vanish.** Grab a tumbling wreck and its spin is shared with you; only a push against it (torque) removes it.

WORDS TO KNOW

Δv (delta-v) is a change in velocity, in metres per second: the currency of spaceflight. **Apoapsis** and **periapsis** are the highest and lowest points of an orbit. The glossary at the back has the rest.

ORBITAL PERIOD

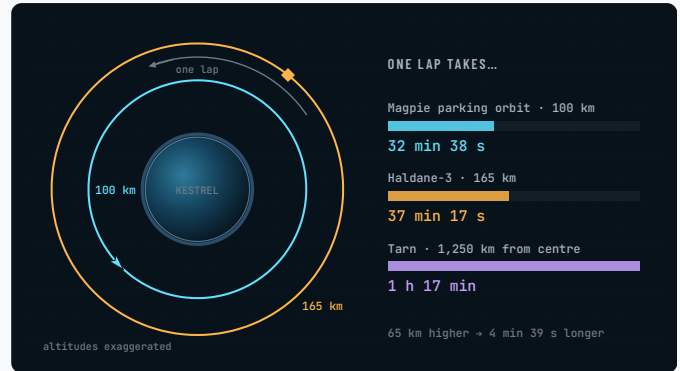
Bigger orbits take longer to go round.

The orbital period is the time it takes to go once around Kestrel. It depends only on the size of the orbit (its semi-major axis, a), not on how heavy you are.

Bigger orbits are slower AND longer, so the period grows quickly with size: double the size and the period becomes almost three times longer.

In the Magpie's 100 km parking orbit one lap takes 32 min 38 s. Haldane-3, only 65 km higher, takes 37 min 17 s. Tarn, 650 km up (1,250 km from Kestrel's centre), takes 77 min 53 s.

$$T = 2\pi \sqrt{a^3 / \mu}$$



TRY IT Tarn is 1,250 km from Kestrel's centre; the parking orbit is 100 km. Tarn's orbit is about 1.8 times as wide. Is its period more or less than 1.8 times as long? Check with the numbers in the note.

You will use this in: C-009 Shakedown Run, C-014 The Silent Observatory.

PROGRADE & RETROGRADE

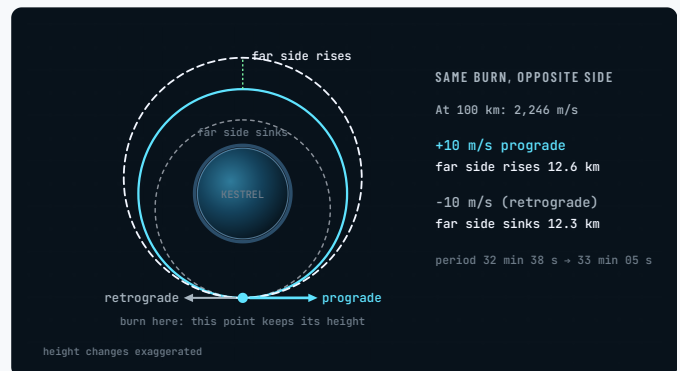
Burn forwards to go higher, backwards to go lower.

Prograde means "the way you are moving". Retrograde is the opposite direction. These are the two most useful burn directions in orbital flight.

A prograde burn adds speed and energy, so the far side of your orbit rises. A retrograde burn removes speed, so the far side sinks. The point where you burned stays at the same height.

It feels backwards at first: to catch something ahead of you, you often slow down, drop into a smaller, faster orbit, and let it come to you.

$$v^2 = \mu (2/r - 1/a) \text{ (vis-viva)}$$



TRY IT You are in a circular orbit. Sketch what one short retrograde burn does to it. Where is the new lowest point?

You will use this in: C-009 Shakedown Run, C-012 Clear the Lane.

APOAPSIS & PERIAPSIS

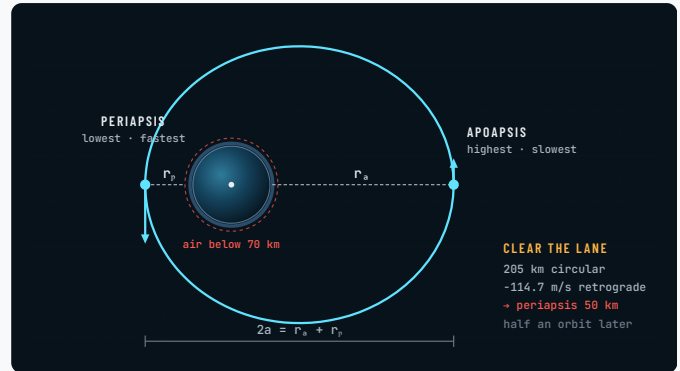
The high point and the low point of an orbit.

Most orbits are slightly oval (elliptical). The highest point is the apoapsis, the lowest is the periapsis. They are always exactly opposite each other, half an orbit apart.

A burn changes the height of the point opposite the burn. Burn prograde at periapsis and the apoapsis rises; burn retrograde at apoapsis and the periapsis drops.

This is why a disposal burn works so well: push a dead stage retrograde and, half an orbit later, its periapsis dips below 60 km into Kestrel's air, where it burns up.

$$r_a + r_p = 2a$$



TRY IT An orbit's apoapsis is 205 km up and its periapsis 50 km up. Kestrel's radius is 600 km. What is the semi-major axis? (Use distances from Kestrel's centre.)

You will use this in: C-011 Thrift Pod, C-012 Clear the Lane, C-019 The Spinning Stage.

HOHMANN TRANSFER

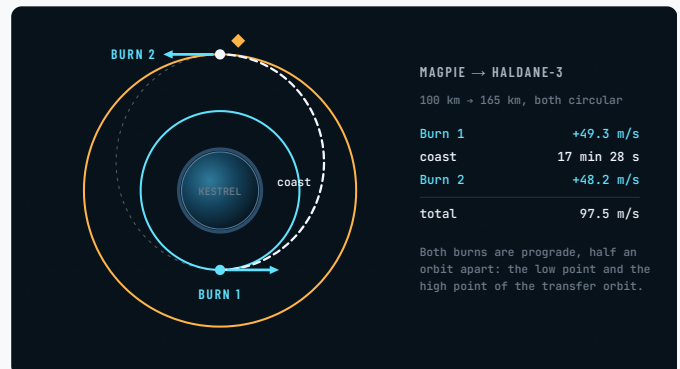
Two burns, half an orbit apart, to move between circular orbits.

A Hohmann transfer is the classic, fuel-saving way to move between two circular orbits. Burn prograde once to stretch your orbit so its far side touches the higher orbit, then burn prograde again when you get there to round it off.

The coast between the burns is exactly half of the transfer orbit, so you can work out how long it takes before you leave.

From the 100 km parking orbit to Haldane-3 at 165 km takes 49.3 m/s, a 17 min 28 s coast, then 48.2 m/s. Going down works the same way with retrograde burns.

$$\Delta v_1 = \sqrt{\mu/r_1}(\sqrt{2r_2/(r_1+r_2)} - 1) \quad t = \pi \sqrt{a^3/\mu}$$



TRY IT Why is the coast between the two burns exactly half of the transfer orbit? Draw it.

You will use this in: C-009 Shakedown Run, C-011 Thrift Pod, C-014 The Silent Observatory, C-016 Inclined to Help.

PHASING

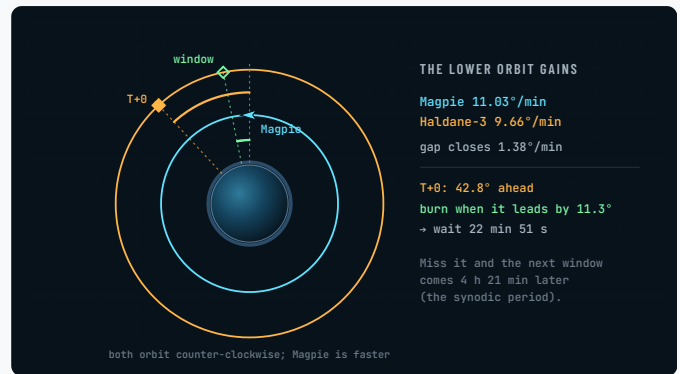
Lower orbits are faster: use that to catch up or wait.

Two craft in different orbits slowly change position relative to each other, because the lower one goes round faster. The angle between them is called the phase angle.

For a Hohmann transfer to meet the target, the target must be a certain angle ahead of you when you burn (or behind you, if it is lower). If the angle is wrong, you wait, and the angle changes a little every orbit.

The window comes round once per “synodic period”. Between 100 km and 165 km that is about 4 h 22 min, so missing a window is expensive in time. A phasing burn trades fuel for time.

$$\text{phase lead} = \pi - n_2 \cdot t_{\text{transfer}} \text{ synodic period} \\ = 2\pi / |n_1 - n_2|$$



TRY IT A target is behind you, in a lower orbit. If you wait, does the gap grow or shrink? Why?

You will use this in: C-011 Thrift Pod.

RELATIVE VELOCITY

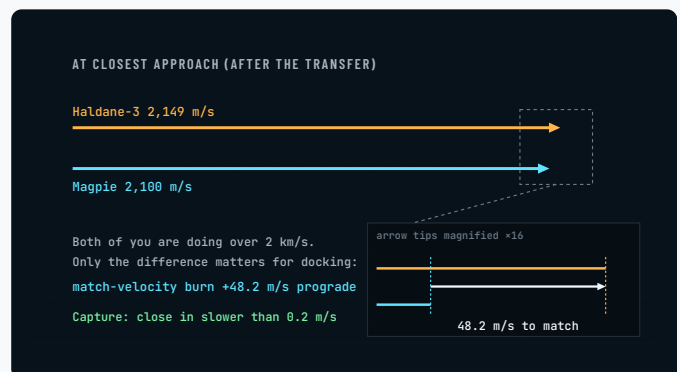
What matters near the target is how fast you are moving compared with it.

Near a target, both of you are doing over 2 km/s around Kestrel. That speed does not matter for docking. What matters is the difference between your velocity and the target's: the relative velocity.

At closest approach after a transfer you might be passing the target at 30-50 m/s. The match-velocity burn removes that difference, so the target seems to hang still beside you.

For a safe capture you want to close in at under 0.2 m/s, slower than a careful walk. Gentle and patient wins.

$$v_{\text{rel}} = v_{\text{you}} - v_{\text{target}}$$



TRY IT Two cars on a motorway both travel at 110 km/h in the same direction. What is their relative speed? How is that like the Magpie beside a wreck?

You will use this in: C-009 Shakedown Run, C-014 The Silent Observatory.

REFERENCE FRAMES

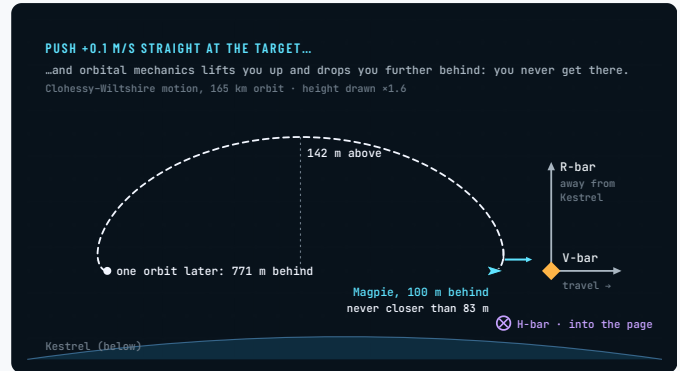
The same motion looks different depending on where you watch from.

On the orbital map you watch from far away, with Kestrel in the middle. In proximity operations you watch from the target, using the LVLH frame: R-bar points up away from Kestrel, V-bar points along the direction of travel, H-bar points out of the orbital plane.

In the target's frame orbital mechanics looks strange. Thrust straight at a target that is ahead of you and you do not fly straight in: you rise above it, slow down and drift back behind it. The extra speed raised your orbit, and a higher orbit is slower.

Holding station on V-bar (straight ahead or behind) is the calmest place to wait: the target turns, and the approach corridor of the point you want comes round to you.

$$\hat{x} = \hat{r} \quad \hat{y} = \hat{h} \times \hat{r} \quad \hat{z} = \hat{h}$$



TRY IT In Proximity, far from the target, give one gentle push towards a target straight ahead (V-bar). Predict which way you will drift, then watch.

You will use this in: C-009 Shakedown Run, C-014 The Silent Observatory, C-016 Inclined to Help.

CLOSEST APPROACH

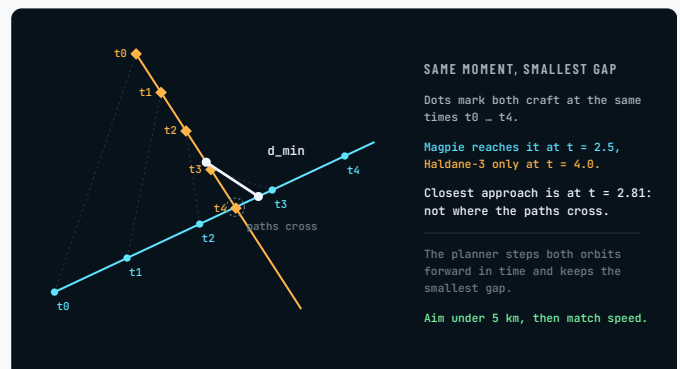
Where two moving things come nearest, which is not where the orbits cross.

Two orbits can cross on the map without the craft ever meeting, because you have to be at the crossing point at the same moment. The closest approach is the time and distance where you really come nearest.

The planner calculates it by stepping both craft forward in time and finding the smallest gap. A few seconds of difference in a burn can move it by kilometres.

Aim for under 5 km. Closer is better, but the match-velocity burn and the RCS can fix the last kilometre.

$$d_{\min} = \min \text{ over } t \text{ of } |r_{\text{you}}(t) - r_{\text{target}}(t)|$$



TRY IT Two orbits cross on the map. Does that mean the craft will meet? What else has to be true?

You will use this in: C-009 Shakedown Run, C-012 Clear the Lane.

ROCKET EQUATION & MASS

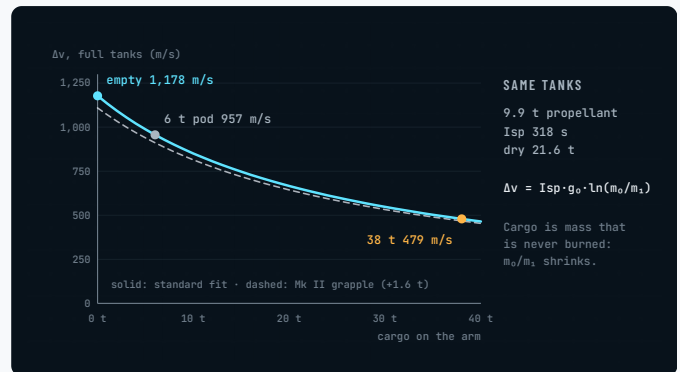
Every tonne you carry costs Δv .

A rocket works by throwing propellant out of the back. How much speed change (Δv) you get depends on how fast the exhaust leaves (Isp) and on the ratio of the full mass to the empty mass.

Add mass that is not propellant (a heavier grapple, or 38 t of observatory on the end of the arm) and the ratio shrinks. The Magpie has about 1,180 m/s empty but only about 480 m/s with Haldane-3 attached, from the same tanks.

Heavier also means slower to speed up: the same burn takes much longer with cargo, so a long burn has to start well before its node.

$$\Delta v = I_{sp} \cdot g_0 \cdot \ln(m_0 / m_1)$$



TRY IT Explain, using the formula, why 38 t of cargo cuts the Magpie's Δv by more than half even though the tanks hold the same propellant.

You will use this in: C-011 Thrift Pod, C-012 Clear the Lane, C-014 The Silent Observatory, C-019 The Spinning Stage.

CENTRE OF MASS

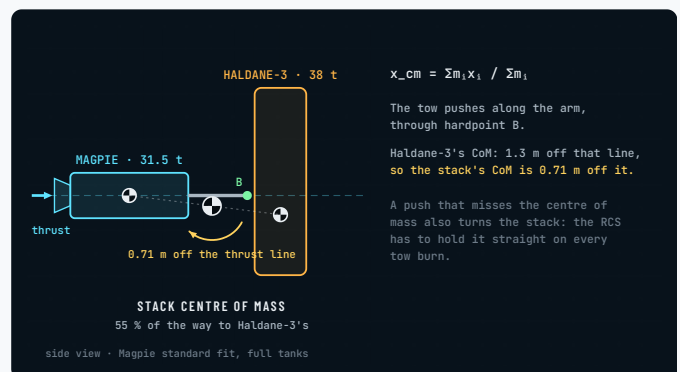
Push through the centre of mass to move without spinning.

The centre of mass is the balance point of an object. A push that passes through it moves the object without turning it. A push that misses it also makes it rotate.

When you grab a target, the tug and target become one stack with a new centre of mass somewhere between them. Your main engine now pushes off-centre, so the stack wants to turn as you burn.

Grabbing a hardpoint a few metres from the target's centre of mass (like Haldane-3's truss hardpoint B) also turns the tumble into a twist on your arm. That is why the grapple has a torque rating.

$$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$$



TRY IT Balance a ruler on your finger, then tape a coin to one end. Where is the balance point now? What does that tell you about the stack after a capture?

You will use this in: C-014 The Silent Observatory, C-019 The Spinning Stage.

ANGULAR MOMENTUM

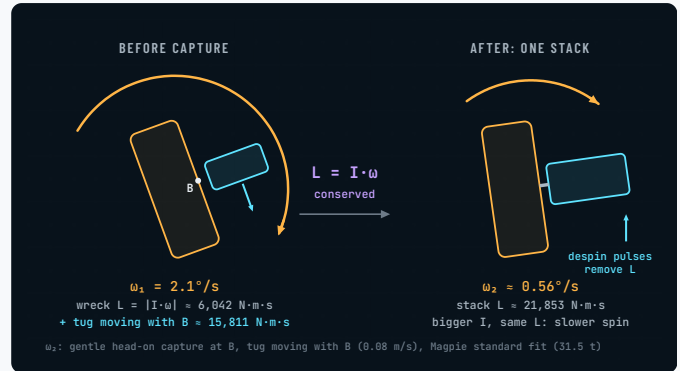
Spin cannot vanish: it is shared out, or removed with torque.

A spinning object keeps its angular momentum unless something twists it. Angular momentum is how hard something is to turn (its moment of inertia, I) times how fast it spins (ω).

When you grapple a tumbling hull, the tug joins the spin. The stack has a bigger moment of inertia, so it spins more slowly than the target did, but the angular momentum is the same.

To stop the spin you need torque: short RCS pulses that push against the rotation. Each pulse removes a fixed amount of angular momentum, about 1,400 N·m·s for the Magpie's thruster couple, so a heavy, fast wreck takes several pulses while a light one is nearly stopped by the capture itself.

$$L = I \omega \quad I_1 \omega_1 = I_2 \omega_2$$



TRY IT A spinning skater pulls their arms in and spins faster. Is grabbing a wreck with the Magpie more like arms in, or arms out?

You will use this in: C-014 The Silent Observatory, C-019 The Spinning Stage.

PLANE CHANGE

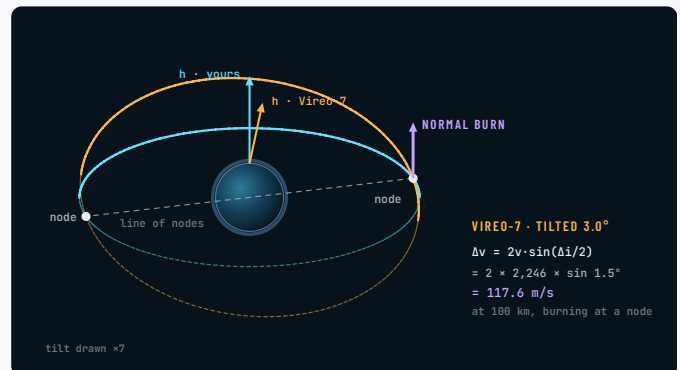
Tilting an orbit is expensive. Do it where the planes cross.

Every orbit lies in a flat plane through the centre of Kestrel. Two planes that are tilted against each other cross along a line: the line of nodes.

A normal burn (at right angles to your orbit) tilts your plane, but only if you make it at a node. Anywhere else it also twists the orbit in a way you did not want. A pure normal burn changes the tilt without changing your period.

Plane changes cost a lot because you are turning your whole velocity. A 3° change at 100 km costs 118 m/s. Do it where you are moving slowest, or combine it with another burn, and it costs less.

$$\Delta v = 2 v \sin(\Delta i / 2)$$



TRY IT A 3° tilt at 100 km costs 118 m/s. Would the same tilt cost more or less higher up, where you move more slowly?

You will use this in: C-016 Inclined to Help.

ECLIPSE

Low orbits spend a third of every lap in Kestrel's shadow.

Kestrel blocks the sun for part of every orbit. In the shadow your solar panels give no power, the hull cools quickly, and a dark target is much harder to see.

At 100 km you spend about 32 % of each orbit in shadow, roughly 10 minutes. Higher up the shadow covers a smaller part of the orbit.

Good pilots plan their arrival so the close approach and capture happen in sunlight, with time to spare before the next sunset.

in shadow if $\mathbf{r} \cdot \hat{\mathbf{s}} < 0$ and $|\mathbf{r} - (\mathbf{r} \cdot \hat{\mathbf{s}})\hat{\mathbf{s}}| < R$



TRY IT Why might a craft in a higher orbit spend a smaller part of each lap in Kestrel's shadow?

You will use this in: C-016 Inclined to Help.

SIX CONTRACTS

The contracts open in this order as your career grows. Each has two pages in this guide: the situation as the game briefs it, then questions for before and after you fly.

CONTRACT	TARGET	WHERE	THE JOB	DIFFICULTY
C-009 Shakedown Run	KS-Relay 4 Communications relay	Low Kestrel orbit · 150 km	Capture only	
C-011 Thrift Pod	Thrift-2 Propellant pod	Low Kestrel orbit · 110 km	Tow to Tarn Yard	
C-012 Clear the Lane	Corvid-U Spent upper stage (R/B)	Hesper debris band · 205 km	Disposal (deorbit)	
C-014 The Silent Observatory	Haldane-3 Deep field observatory	Kestrel orbit · 165 km	Tow to Tarn Yard	
C-016 Inclined to Help	Vireo-7 Weather satellite	Inclined orbit · 180 km, 3°	Capture only	
C-019 The Spinning Stage	Corvid-H Heavy upper stage (R/B)	Above the Hesper band · 240 km	Disposal (deorbit)	

BEFORE EVERY CONTRACT

1. Read the briefing in the game, and the dossier: what is known, and what is not?
2. Sketch Kestrel, your orbit and the target's. Where is the target compared with you?
3. Answer the predictions on the contract's page before the game asks you.
4. Decide what you will watch for in the review.

AFTER EVERY CONTRACT

1. What was the biggest divergence in the review, and what caused it?
2. Which predictions did you get right, and which surprised you?
3. Which grade was higher, planning or piloting? What would raise the other?
4. What will you do differently next time?

C-009 • KESTREL SIGNAL CO.

SHAKEDOWN RUN

A small relay satellite has gone quiet and is turning slowly. Catch it and hold it steady: your first job in the Magpie.

TARGET

KS-Relay 4

JOB

Capture only

WHERE

Low Kestrel orbit • 150 km

DIFFICULTY



YOUR ORBIT

100 km circular

TARGET ORBIT

150 km circular

AT THE START

25° ahead

MASS

0.9 t

TUMBLE

1.2°/s

DEADLINE

8 h

PAYOUT

12,000 CR

ADRIFT

9 days

THE SITUATION, AS BRIEFED BY KESTREL SIGNAL CO.

Welcome aboard, Magpie. Your first job is an easy one, on purpose. KS-Relay 4 is a small communications satellite, under a tonne, that stopped answering nine days ago. Its owners want it back on the bench in one piece.

The relay is in a circular orbit 50 km above yours and a little ahead of you. You cannot just point at it and fly there: in orbit, speeding up makes you climb, and climbing makes you slower. The trick is a two-burn transfer. Burn forwards once to stretch your orbit up to the relay's height, then burn again when you arrive to match its speed.

It is turning about 1.2° per second, around an axis square to its orbit, so its launch ring sweeps past you once every few minutes. That is gentle enough for the standard grapple. Its launch adapter ring is the usual grip for servicing. Watch the satellite for a while before you close in, so you know when the ring will face you.

Before every burn you will be asked to predict what it will do. Guess honestly. You will compare your guess with what really happened in the review, and that is where the learning is.

THE DOSSIER: KNOWN

- Mass 0.9 t
- Circular orbit at 150 km, 50 km above you
- Starts about 25° ahead of you
- Turning about 1.2°/s around an axis square to its orbit
- Launch adapter ring (A): the standard servicing grip
- Feed horn tower (B): not load-rated, do not grab

THE DOSSIER: UNKNOWN

- Kestrel-deck lifting lug (C): condition unknown until scanned
- Exact spin axis: observe the tumble to pin it down
- When the adapter ring next faces you

1 crew log can be recovered on this contract.

COMPETING OBJECTIVES

Relay integrity	≥ 90 %
Fuel reserve	≥ 1,000 m/s
Capture before deadline	by 8 h

CONCEPTS YOU WILL PRACTISE

Orbital period

Prograde & retrograde

Hohmann transfer

Relative velocity

Reference frames

Closest approach

BEFORE YOU PLAY

1. The relay is higher than you and ahead of you. Draw Kestrel, your orbit and the relay's orbit. Mark where you think you should burn and where you will meet the relay.
2. To reach a higher orbit, will you burn forwards (prograde) or backwards (retrograde)? Why?
3. The relay turns about 1.2° every second. Roughly how long does one full turn take? Why does that matter when you want to grab one particular part of it?

PREDICT ON PAPER: QUESTIONS THE GAME MAY ASK YOU

Circle your answer before you fly. The game asks before each committed burn, and in Proximity before you grab. A different plan may bring different questions.

BURN 1 • TRANSFER

After this prograde burn, your orbital period around Kestrel will be...

- ☐ Shorter
- ☐ Longer
- ☐ About the same

BURN 2 • MATCH VELOCITY

After the match-velocity burn, KS-Relay 4 will appear to...

- ☐ Hang almost still beside you
- ☐ Drift away ahead of you
- ☐ Drop away behind you

PROXIMITY • BEFORE YOU GRAPPLE

KS-Relay 4 tumbles at $1.2^\circ/\text{s}$. The moment the grapple closes, how fast will the whole stack spin?

- ☐ Slower than the target spins now
- ☐ Faster than the target spins now
- ☐ Exactly as fast as before

AFTER YOU PLAY

1. Find the biggest difference in the review's Prediction vs outcome table. What caused it?
2. Which of your predictions were right? For one you got wrong, explain in your own words what really happened.
3. Describe how the relay looked from the Magpie when you matched velocity. Was it still, drifting ahead or dropping behind? Why?
4. Was your planning grade or your piloting grade higher? What one thing would raise the lower one?

Bonuses on offer: Gentle capture ($\leq 0.10 \text{ m/s}$) • Every prediction right

NOTES

THRIFT POD

A fuel pod was cut loose below you and is creeping up from behind. Drop down to meet it, then tow it out to Tarn Yard.

TARGET

Thrift-2

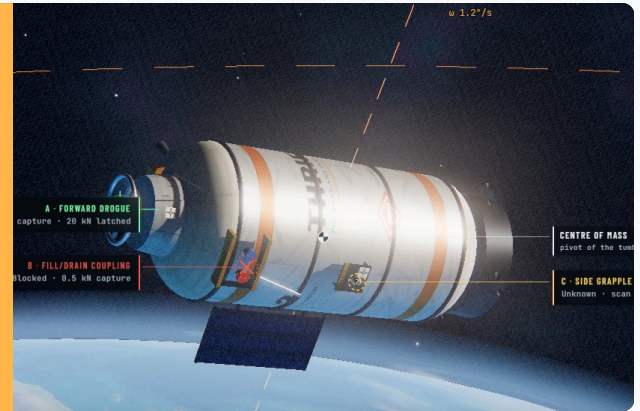
JOB

Tow to Tarn Yard

WHERE

Low Kestrel orbit • 110 km

DIFFICULTY



YOUR ORBIT
180 km circular

TARGET ORBIT
110 km circular

AT THE START
46° behind

MASS
6 t

TUMBLE
1.2°/s

DEADLINE
6 h 30 min

PAYOUT
22,500 CR

ADRIFT
3 days

THE SITUATION, AS BRIEFED BY THRIFT PROPELLANT CO-OP

Tarn Yard is running low on propellant, and the next delivery is sitting in the wrong orbit. A Thrift Co-op shuttle had to cut its fuel pod loose three days ago. The pod is fine: sealed, cold, no engine. It just needs a lift.

The pod is 70 km below you and about 46° behind. Here is the part that feels backwards: because it is lower, it is going round faster, and it is catching up with you. You do not chase it. You wait for the right moment, then burn retrograde to drop down and meet it.

Once you have it on the arm, burn prograde to stretch your orbit out to Tarn. Time the tow so Tarn is in the right place when you get there; the Yard's tenders will meet you at the edge of Tarn's sphere of influence if you arrive slower than 300 m/s.

Six tonnes is a light tow, but you will feel it: the same burn takes longer with the pod attached.

THE DOSSIER: KNOWN

- Mass about 6 t, mostly propellant
- Circular orbit at 110 km, 70 km below you
- Starts 46° behind you, gaining every orbit
- Forward drogue (A): a viable grip
- Fill/drain coupling (B): pressurised, never clamp it
- Tarn Yard tenders take tows arriving under 300 m/s

THE DOSSIER: UNKNOWN

- Side grapple fixture (C): condition unknown until scanned
- Exact tumble rate and axis (radar says about 1.2°/s)
- When the tow window to Tarn opens after capture

2 crew logs can be recovered on this contract.

COMPETING OBJECTIVES

Pod integrity	$\geq 90\%$
Fuel reserve	≥ 640 m/s
Deliver before deadline	by 6 h 30 min

CONCEPTS YOU WILL PRACTISE

Phasing

Hohmann transfer

Apoapsis & periapsis

Rocket equation & mass

BEFORE YOU PLAY

1. The pod is below you and behind you. Which of you goes round Kestrel faster, and how do you know?
2. Instead of chasing the pod, the briefing tells you to wait. What are you waiting for?
3. With the pod on the arm, will the same burn take longer, shorter or the same time? Explain using what you know about mass and force.
4. When you tow the pod to Tarn, why does it matter where Tarn is when you set off?

PREDICT ON PAPER: QUESTIONS THE GAME MAY ASK YOU

Circle your answer before you fly. The game asks before each committed burn, and in Proximity before you grab. A different plan may bring different questions.

BURN 1 • DROP TO THE POD

When you reach Thrift-2's height, how will your speed compare with the target's?

- ☐ Slower than the target
- ☐ Faster than the target
- ☐ About the same speed

BURN 2 • MATCH VELOCITY

After the match-velocity burn, Thrift-2 will appear to...

- ☐ Hang almost still beside you
- ☐ Drift away ahead of you
- ☐ Drop away behind you

PROXIMITY • BEFORE YOU GRAPPLE

Thrift-2 tumbles at 1.2°/s. The moment the grapple closes, how fast will the whole stack spin?

- ☐ Slower than the target spins now
- ☐ Faster than the target spins now
- ☐ Exactly as fast as before

TOW • TO TARN

After this tow burn, how high will the high point of your orbit reach?

- ☐ Short of Tarn's orbit
- ☐ Level with Tarn's orbit (within 30 km)
- ☐ Beyond Tarn's orbit

AFTER YOU PLAY

1. How long did you wait before the first burn? What changed during the wait?
2. Compare your empty burns with the tow burn. How much longer did the tow take, and why?
3. How fast were you going relative to Tarn when you arrived? How close was that to the 300 m/s limit?
4. Write one sentence that would help a friend believe "the lower one wins the race".

Bonuses on offer: Gentle capture (≤ 0.10 m/s) • Delivered with 2 h to spare • Fuel reserve ≥ 680 m/s

NOTES

CLEAR THE LANE

A dead rocket stage is tumbling through the busiest lane in the Hesper band. Bring it down clean, and climb back out before you follow it.

TARGET

Corvid-U

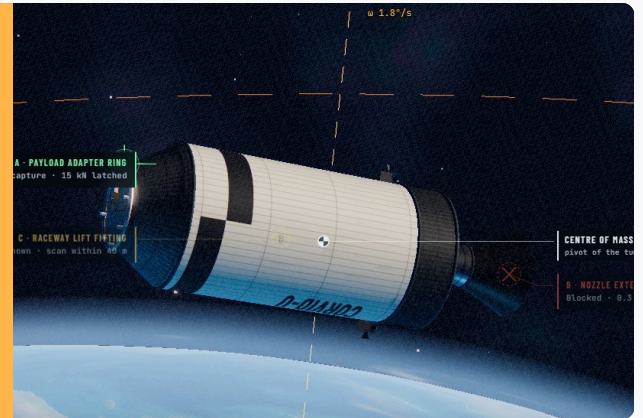
WHERE

Hesper debris band • 205 km

JOB

Disposal (deorbit)

DIFFICULTY



YOUR ORBIT
100 km circular

TARGET ORBIT
205 km circular

AT THE START
72° ahead

MASS
4.2 t

TUMBLE
1.8°/s

DEADLINE
5 h

PAYOUT
26,000 CR

ADRIFT
3,290 days

THE SITUATION, AS BRIEFED BY HESPER LANE OFFICE • SALVAGE GUILD

Nine years ago a Corvid upper stage delivered its payload and then failed to relight for its disposal burn. It has been turning end over end in the Hesper debris band ever since: 4.2 tonnes of empty aluminium in the middle of a busy traffic lane. The Lane Office wants it gone.

Gone means down. Capture the stage, then burn retrograde with it on the arm. Slowing down lowers the far side of the orbit; push the lowest point below 60 km and Kestrel's air will finish the job half an orbit later.

The catch: until you let go, you are on that orbit too. Release the stage, then burn prograde right away to lift your own lowest point back above 70 km. Leave it too late and you will meet the air before the stage does.

Be gentle with the hull. A cracked stage sheds new fragments into the lane, which is the opposite of the job.

THE DOSSIER: KNOWN

- Mass 4.2 t, tanks empty
- Circular orbit at 205 km, inside the Hesper band
- Turning end over end at about 1.8°/s
- Payload adapter ring (A): viable, but far forward of the centre of mass
- Nozzle extension (B): thin metal, do not grab
- Disposal: its lowest point below 60 km, yours above 70 km

THE DOSSIER: UNKNOWN

- Raceway lift fitting (C): condition unknown until scanned
- Exact spin axis

1 crew log can be recovered on this contract.

COMPETING OBJECTIVES

Stage integrity	≥ 90 %
Fuel reserve	≥ 800 m/s
Disposal before deadline	by 5 h

CONCEPTS YOU WILL PRACTISE

Apoapsis & periapsis

Prograde & retrograde

Rocket equation & mass

Closest approach

BEFORE YOU PLAY

1. You will burn retrograde with the stage on the arm. Where will its lowest point end up: where you burn, or somewhere else? Sketch it.
2. After you let go of the stage, what happens to your own orbit? Will you be safe?
3. To lift your lowest point back above 70 km, where on your orbit would you burn, and in which direction?
4. The stage is in a busy debris band. Why is a gentle capture part of this job, not just a bonus?

PREDICT ON PAPER: QUESTIONS THE GAME MAY ASK YOU

Circle your answer before you fly. The game asks before each committed burn, and in Proximity before you grab. A different plan may bring different questions.

BURN 1 • TRANSFER

After this prograde burn, your orbital period around Kestrel will be...

- ☐ Shorter
- ☐ Longer
- ☐ About the same

BURN 2 • MATCH VELOCITY

After the match-velocity burn, Corvid-U will appear to...

- ☐ Hang almost still beside you
- ☐ Drift away ahead of you
- ☐ Drop away behind you

PROXIMITY • BEFORE YOU GRAPPLE

Corvid-U tumbles at 1.8°/s. The moment the grapple closes, how fast will the whole stack spin?

- ☐ Slower than the target spins now
- ☐ Faster than the target spins now
- ☐ Exactly as fast as before

DEORBIT • WITH THE STAGE

After this retrograde burn, where will the lowest point of the orbit be?

- ☐ Right here, where you burn
- ☐ Half an orbit away, on the far side of Kestrel
- ☐ A quarter of an orbit ahead

CLIMB • TUG ALONE AFTER RELEASE

Your lowest point is now 50 km. Where should you burn prograde to lift it above 70 km for the least propellant?

- ☐ At apoapsis, the high point
- ☐ At periapsis, the low point
- ☐ Anywhere: it makes no difference

AFTER YOU PLAY

1. How low did the stage's periapsis go? How did that compare with your prediction?
2. How long did you wait between releasing the stage and climbing? Why did that matter?
3. Did you trigger any keep-out warnings? What were you doing at the time?
4. Explain why a disposal burn "lowers the far side" of the orbit.

Bonuses on offer: Stage intact: no new fragments • No keep-out violations • Fuel reserve ≥ 820 m/s

NOTES

C-014 · HALDANE INSTITUTE, TARN

THE SILENT OBSERVATORY

Haldane-3 lost power 41 days ago and is tumbling at 165 km. Tow it to Tarn Yard and keep the primary mirror intact.

TARGET

Haldane-3

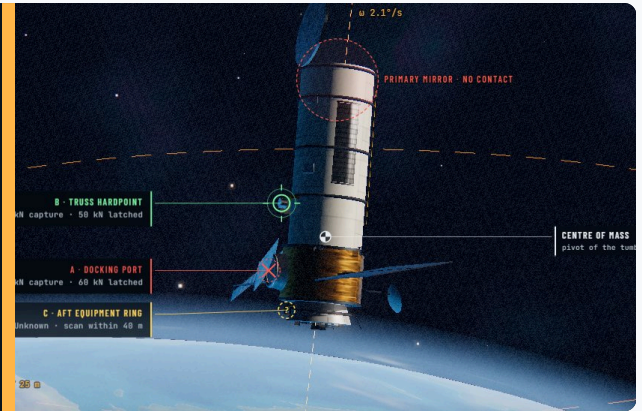
JOB

Tow to Tarn Yard

WHERE

Kestrel orbit · 165 km

DIFFICULTY



YOUR ORBIT

100 km circular

TARGET ORBIT

165 km circular

AT THE START

43° ahead

MASS

38 t

TUMBLE

2.1°/s

DEADLINE

7 h 20 min

PAYOUT

48,200 CR

ADRIFT

41 days

THE SITUATION, AS BRIEFED BY HALDANE INSTITUTE, TARN

Haldane-3 is a 38-tonne observatory. Its last crew left in a hurry 41 days ago, after a power fault they could not fix. Before they went, they closed the telescope door to protect the mirror, but a micrometeoroid has since sprung the latch and the door now hangs open. The Haldane Institute wants her back at Tarn Yard, mirror and all. The survey data she carries is priceless.

She is tumbling at 2.1° per second. Her docking port, A, is blocked by a sun shield that was folded across it when the crew left. Truss hardpoint B takes a gentle capture (4 kN) and, once the grapple latches, the full pull of the tow (50 kN), so it should work. The aft equipment ring, C, is a question mark: the telemetry is incomplete. Get within 40 m and scan it if you want to know.

Getting there is a normal two-burn transfer. Getting back is the hard part. With 38 tonnes on the arm, the Magpie has less than half the Δv she has when empty, and the tow burn lasts about six minutes. A long burn spreads its push around the orbit instead of delivering it all at the best point, so it buys a little less than the plan promises: watch your path, not just the gauge, or split the tow into two shorter burns one orbit apart. Plan it carefully, and keep a fuel reserve.

Go slowly near the open end of the telescope. A bump on the mirror is the one thing the Institute will not forgive.

THE DOSSIER: KNOWN

- Mass 38 t: close to the standard grapple's 40 t limit
- Circular orbit at 165 km, 65 km above you
- Tumbling at 2.1°/s (one turn every 2 min 51 s), nutation about $\pm 4^\circ$
- Docking port A: blocked by a folded sun shield. Do not touch
- Truss hardpoint B: viable. Rated 4 kN at capture and 50 kN latched: a full-thrust tow pulls about 25 kN through it ($38 \text{ t} \times 0.66 \text{ m/s}^2$)
- Aperture door: closed by the crew, since sprung open. The mirror is exposed

THE DOSSIER: UNKNOWN

- Aft equipment ring C: telemetry incomplete. Scan it from within 40 m
- Exact spin axis: observe the tumble to refine it
- When the tow window to Tarn opens after capture

7 crew logs can be recovered on this contract.

COMPETING OBJECTIVES

Instrument integrity	$\geq 90 \%$
Fuel reserve	$\geq 400 \text{ m/s}$
Deliver before deadline	by 7 h 20 min

CONCEPTS YOU WILL PRACTISE

Orbital period

Relative velocity

Reference frames

Angular momentum

Centre of mass

Rocket equation & mass

Hohmann transfer

BEFORE YOU PLAY

1. Haldane-3 weighs 38 t. The Magpie weighs about 31 t when fully fuelled. What do you expect the tow burn to feel like compared with your other burns?
2. Look at the three attachment points in the dossier. Which would you choose, and what would you want to know first?
3. When the grapple closes on a tumbling observatory, what happens to its spin? Where does the spin go?
4. The tow is a long burn. Why might a long burn give you slightly less than the plan promises?

PREDICT ON PAPER: QUESTIONS THE GAME MAY ASK YOU

Circle your answer before you fly. The game asks before each committed burn, and in Proximity before you grab. A different plan may bring different questions.

BURN 1 • TRANSFER

After this prograde burn, your orbital period around Kestrel will be...

- ☐ Shorter
- ☐ Longer
- ☐ About the same

BURN 2 • MATCH VELOCITY

After the match-velocity burn, Haldane-3 will appear to...

- ☐ Hang almost still beside you
- ☐ Drift away ahead of you
- ☐ Drop away behind you

PROXIMITY • BEFORE YOU GRAPPLE

Haldane-3 tumbles at $2.1^\circ/\text{s}$. The moment the grapple closes, how fast will the whole stack spin?

- ☐ Slower than the target spins now
- ☐ Faster than the target spins now
- ☐ Exactly as fast as before

TOW • TO TARN (HEAVY)

After this tow burn, how high will the high point of your orbit reach?

- ☐ Short of Tarn's orbit
- ☐ Level with Tarn's orbit (within 30 km)
- ☐ Beyond Tarn's orbit

AFTER YOU PLAY

1. Which attachment point did you use? Did you scan ring C? What did you find?
2. How fast was the stack spinning just after capture, and how many despin pulses did you need?
3. How much fuel reserve did you have at the end? Which part of the job used the most Δv ?
4. Read the recovered logs in the journal. How does knowing the crew's story change how you think about the mirror?

Bonuses on offer: Mirror intact (100 % integrity) • Capture at $\leq 0.10 \text{ m/s}$ • Fuel reserve $\geq 460 \text{ m/s}$

NOTES

INCLINED TO HELP

A weather satellite in a tilted orbit has lost control days before storm season. Match its plane, catch it, and steady it for the repair crew.

TARGET

Vireo-7

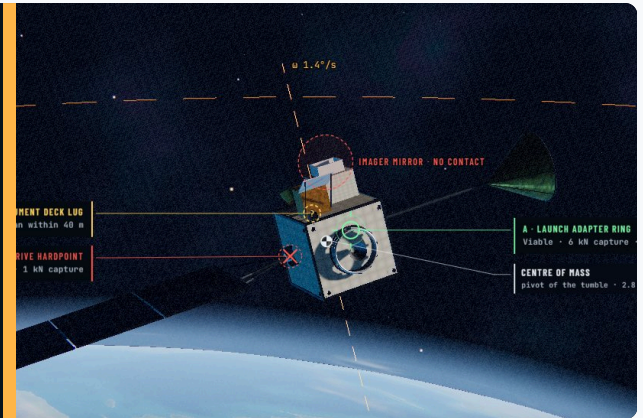
JOB

Capture only

WHERE

Inclined orbit • 180 km, 3°

DIFFICULTY



YOUR ORBIT
100 km circular

TARGET ORBIT
180 km, tilted 3°

AT THE START
43° ahead

MASS
2.8 t

TUMBLE
1.4°/s

DEADLINE
5 h 30 min

PAYOUT
34,000 CR

ADRIFT
6 days

THE SITUATION, AS BRIEFED BY KESTREL WEATHER SERVICE

Vireo-7 watches the southern ocean for storms, and it has stopped watching. A sensor cover stuck after an eclipse, the attitude system got confused, and the satellite is now turning at 1.4° per second with its imager pointing at nothing. Storm season starts in five days.

Vireo-7's orbit is tilted 3° to yours, on purpose: the tilt lets it see further south. Two tilted orbits only cross along one line, the line of nodes. A burn at right angles to your orbit (a normal burn) can tilt your plane to match, but only if you make it at a node.

Plane changes are expensive: you are turning your whole velocity, more than 2 km/s of it. The smart move is to combine the tilt with a burn you were going to make anyway. Arrive at a node and do both in one go, and you will save a lot of propellant.

Catch Vireo-7 and stop the spin. A Weather Service crew will take it from there.

THE DOSSIER: KNOWN

- Mass 2.8 t
- Circular orbit at 180 km, tilted 3° to yours
- Tumbling at 1.4°/s
- Launch adapter ring (A): a viable grip
- Array drive hardpoint (B): blocked
- Imager scan mirror on the Kestrel-facing deck: never touch it

THE DOSSIER: UNKNOWN

- Where the two orbital planes cross (the line of nodes): find it on the map
- Instrument deck lug (C): condition unknown until scanned
- Exact spin axis

2 crew logs can be recovered on this contract.

COMPETING OBJECTIVES

Imager integrity	≥ 90 %
Fuel reserve	≥ 960 m/s
Capture before deadline	by 5 h 30 min

CONCEPTS YOU WILL PRACTISE

Plane change

Hohmann transfer

Reference frames

Eclipse

BEFORE YOU PLAY

1. Vireo-7's orbit is tilted 3° to yours. Where do the two orbits actually cross?
2. A burn at right angles to your orbit (normal) tilts your plane. Why does it have to happen at a node?
3. Would it be cheaper to tilt your orbit first and then transfer, or to do both together in one burn? Make a guess, then test it.
4. Will you arrive in sunlight or in Kestrel's shadow? Why does it matter for the capture?

PREDICT ON PAPER: QUESTIONS THE GAME MAY ASK YOU

Circle your answer before you fly. The game asks before each committed burn, and in Proximity before you grab. A different plan may bring different questions.

BURN 1 • TRANSFER AT THE ASCENDING NODE

When you reach Vireo-7's height, how will your speed compare with the target's?

- ☐ Slower than the target
- ☐ Faster than the target
- ☐ About the same speed

BURN 2 • MATCH + PLANE CHANGE AT THE DESCENDING NODE

This one burn both reshapes your orbit (prograde part) and tilts it (normal part). Which part costs more Δv ?

- ☐ The tilt (normal part)
- ☐ Reshaping the orbit (prograde part)
- ☐ About the same

PROXIMITY • BEFORE YOU GRAPPLE

Vireo-7 tumbles at $1.4^\circ/\text{s}$. The moment the grapple closes, how fast will the whole stack spin?

- ☐ Slower than the target spins now
- ☐ Faster than the target spins now
- ☐ Exactly as fast as before

AFTER YOU PLAY

1. How much Δv did you use before capture? How did that compare with the 200 m/s bonus line?
2. Look at your arrival burn's prograde and normal parts. Why is the total less than the two added together?
3. How did the engineering view (V) help you see the tilt?
4. If you had to tilt by 6° instead of 3° , roughly what would happen to the cost?

Bonuses on offer: Rendezvous for ≤ 200 m/s (combined plane change) • Gentle capture (≤ 0.10 m/s) • Every prediction right

NOTES

THE SPINNING STAGE

An 11-tonne rocket stage is spinning at 4.5° a second, and it has already thrown off two tugs. Bring the heavy grapple, catch it, stop the spin, and put it in the sea.

TARGET

Corvid-H

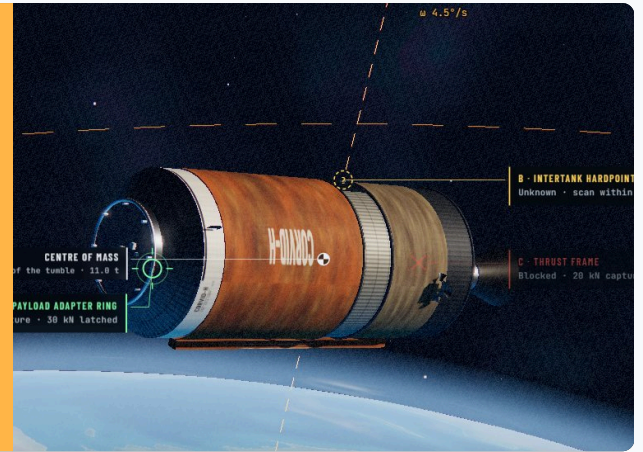
WHERE

Above the Hesper band • 240 km

JOB

Disposal (deorbit)

DIFFICULTY



YOUR ORBIT
100 km circular

TARGET ORBIT
240 km circular

AT THE START
108° ahead

MASS
11 t

TUMBLE
4.5°/s

DEADLINE
4 h

PAYOUT
41,500 CR

ADRIFT
412 days

THE SITUATION, AS BRIEFED BY CORVID LAUNCH SYSTEMS

This one has a reputation. Corvid-H flight 9 left its heavy upper stage at 240 km, and a leaking pipe set it spinning at 4.5° per second. Two tugs have tried to catch it this year. Both bounced off: their grapples were never rated for a spin that fast.

You will need the Heavy grapple Mk II, whose torque-limited wrist can hold a hull turning at up to 5° per second. Even so, pick your grip with care. The payload adapter ring is the obvious one, but out at the end of the stage it whips round at half a metre per second. The only part of a spinning object that holds still is on its spin axis.

When the grapple closes, the spin does not vanish. It is shared between the stage and your tug, so the whole stack turns more slowly, but it still turns. Fire despin pulses against it until the stack is steady.

Then it is a disposal, like clearing the lane: retrograde until the lowest point is under 60 km, let go, and climb back above 70 km before the air catches you too. With 11 tonnes on the arm, give yourself plenty of time for the burn.

THE DOSSIER: KNOWN

- Mass 11 t
- Circular orbit at 240 km, above the Hesper band
- Tumbling end over end at $4.5^\circ/\text{s}$, steady (one turn every 80 s)
- Payload adapter ring (A): viable, but it whips round at about 0.5 m/s
- Thrust frame (C): blocked
- Two capture attempts with standard grapples failed
- Heavy grapple Mk II required

THE DOSSIER: UNKNOWN

- Intertank hardpoint (B), right on the spin axis: condition unknown until scanned
- How much monoprop the despin will take

2 crew logs can be recovered on this contract.

COMPETING OBJECTIVES

Stage integrity	$\geq 85\%$
Fuel reserve	$\geq 625\text{ m/s}$
Disposal before deadline	by 4 h

CONCEPTS YOU WILL PRACTISE

Angular momentum

Centre of mass

Apoapsis & periapsis

Rocket equation & mass

BEFORE YOU PLAY

1. The stage turns once every 80 seconds. Its payload adapter ring is far from the spin axis. How fast do you think the ring is moving?
2. The briefing says the only part of a spinning object that holds still is on its spin axis. Which attachment point might that be, and how will you find out?
3. After capture the stack still turns. Will it turn faster or slower than the stage did alone? Why?
4. With 11 t on the arm, how will the disposal burn compare with Clear the Lane?

PREDICT ON PAPER: QUESTIONS THE GAME MAY ASK YOU

Circle your answer before you fly. The game asks before each committed burn, and in Proximity before you grab. A different plan may bring different questions.

BURN 1 • TRANSFER

After this prograde burn, your orbital period around Kestrel will be...

- ☐ Shorter
- ☐ Longer
- ☐ About the same

BURN 2 • MATCH VELOCITY

After the match-velocity burn, Corvid-H will appear to...

- ☐ Hang almost still beside you
- ☐ Drift away ahead of you
- ☐ Drop away behind you

PROXIMITY • BEFORE YOU GRAPPLE

Corvid-H tumbles at 4.5°/s. The moment the grapple closes, how fast will the whole stack spin?

- ☐ Slower than the target spins now
- ☐ Faster than the target spins now
- ☐ Exactly as fast as before

DEORBIT • WITH THE STAGE

After this retrograde burn, where will the lowest point of the orbit be?

- ☐ Right here, where you burn
- ☐ Half an orbit away, on the far side of Kestrel
- ☐ A quarter of an orbit ahead

CLIMB • TUG ALONE AFTER RELEASE

Your lowest point is now 50 km. Where should you burn prograde to lift it above 70 km for the least propellant?

- ☐ At apoapsis, the high point
- ☐ At periapsis, the low point
- ☐ Anywhere: it makes no difference

AFTER YOU PLAY

1. Which point did you grab, and how fast was it moving when you closed the grapple?
2. How many despin pulses did it take? How much monoprop did you have left?
3. Compare this disposal with C-012. What was the same, and what was harder?
4. Two tugs failed to catch this stage before you. Write a short safety note for the next pilot.

Bonuses on offer: Despun in 8 pulses or fewer • No keep-out violations • Stage intact

NOTES

COMPARE AND REPLAY

Use **RETRY WITH CHANGES** to fly a contract again. Change one thing at a time (your burn timing, your attachment point, your approach speed) and compare the reviews.

FIRST FLIGHT	SECOND FLIGHT	THIRD FLIGHT
Planning grade		
Piloting grade		
Predictions right		
Biggest divergence		
What I will change		

WHAT I CHANGED, AND WHAT HAPPENED

CLOSING REFLECTION

1. Which prediction did you find hardest? What would you tell someone about to make it?
2. Explain to a friend why burning forwards can make you go round the planet more slowly.
3. Describe one divergence the review found in your flying. What caused it, and how did you fix it?
4. Why does a heavy tow change every number on the map?
5. What happens to a wreck's spin when you grab it? Use the words "angular momentum" and "shared".
6. Which was harder for you, planning or piloting? Why do you think that is?

YOUR REFLECTION

KEEP GOING

- ☐ Fly every contract, and replay one to raise your lower grade.
- ☐ Get every prediction right on one contract.
- ☐ Capture a target at 0.10 m/s or less.
- ☐ Try the Free flight sandbox: plan a burn, predict, fly it and see.
- ☐ Read every recovered log in the Mission journal.

GLOSSARY

ALIGNMENT WINDOW

The few seconds when a tumbling target's chosen attachment point faces you and is in reach. The Tumble analysis panel counts down to the next one.

ANGULAR MOMENTUM

Spin cannot vanish: it is shared out, or removed with torque.

APOAPSIS & PERIAPSIS

The high point and the low point of an orbit.

ATMOSPHERE LINE (70 KM)

Below 70 km a craft at orbital speed meets Kestrel's air. A periapsis below it means re-entry; a dead stage whose lowest point is under 60 km burns up on its first pass.

ATTACHMENT POINT

A place on a wreck where the grapple can hold: viable, blocked, or unknown until scanned from within 40 m.

BURN

Firing the main engine to change your velocity. Planned burns appear as nodes on the map.

BURN ASSIST

A setting that cuts each burn automatically at its planned Δv . Assisted burns are not scored for piloting.

CAPTURE

Closing the grapple on an attachment point. It needs the point in reach, facing you, and a closing speed of 0.2 m/s or less.

CENTRE OF MASS

Push through the centre of mass to move without spinning.

CLOSEST APPROACH

Where two moving things come nearest, which is not where the orbits cross.

COMPETING OBJECTIVES

The goals every contract balances: the target's integrity, the fuel reserve you keep, and the deadline.

CROSSFEED

Moving main propellant into the RCS tanks (key R in Proximity) when the monoprop runs low.

DESPIN

Stopping the stack's rotation with short RCS pulses (F) after capture, until it turns slower than $0.1^\circ/\text{s}$.

DISPOSAL

Bringing a dead object down so it burns up in Kestrel's air: lower its periapsis below 60 km, release it, then climb back above 70 km yourself.

DIVERGENCE

The difference between what you planned and what really happened. The review traces the biggest one to its cause.

ECLIPSE

Low orbits spend a third of every lap in Kestrel's shadow.

ENGINEERING VIEW

A map mode (V) that draws velocity and gravity arrows, with apsis data.

HOHMANN TRANSFER

Two burns, half an orbit apart, to move between circular orbits.

HOLD POINT

A marked spot ($\diamond$) on V-bar near the target where you can wait at rest before closing in. H sets course for it.

INCLINATION

The tilt of an orbit's plane, in degrees. Vireo-7's orbit is inclined 3° to yours.

ISP (SPECIFIC IMPULSE)

How efficiently an engine uses propellant, in seconds. The Magpie's Vela-2 has an Isp of 318 s.

KEEP-OUT SPHERE

A 25 m safety zone around a wreck. Enter it slowly and only inside the approach corridor.

LVLH FRAME

Local vertical, local horizontal: the target-centred frame used in Proximity, with R-bar, V-bar and H-bar axes.

MANOEUVRE NODE

A planned burn on the map: a time and a Δv split into prograde, radial and normal parts.

MOMENT OF INERTIA

How hard an object is to turn. Mass far from the spin axis adds the most.

MONOPROP

The propellant for the RCS thrusters, kept in its own small tank.

NODE (LINE OF NODES)

Where two tilted orbital planes cross. A plane change works only when made at a node.

NORMAL / ANTI-NORMAL

The burn directions at right angles to your orbital plane. They tilt the orbit.

NUTATION

A slow wobble of a tumbling object's spin axis.

ORBITAL PERIOD

Bigger orbits take longer to go round.

PHASE ANGLE

How far ahead of you (or behind) the target is around the orbit, in degrees.

PHASING

Lower orbits are faster: use that to catch up or wait.

PLANE CHANGE

Tilting an orbit is expensive. Do it where the planes cross.

PROGRADE & RETROGRADE

Burn forwards to go higher, backwards to go lower.

R-BAR, V-BAR, H-BAR

The axes of the target's frame: R-bar points up away from Kestrel, V-bar along the direction of travel, H-bar out of the orbital plane.

RADIAL IN / RADIAL OUT

Burn directions towards or away from Kestrel. They rotate the orbit's shape rather than change its size.

RCS

Reaction control system: the sixteen small thrusters used to move and turn the tug gently in Proximity.

REFERENCE FRAMES

The same motion looks different depending on where you watch from.

RELATIVE VELOCITY

What matters near the target is how fast you are moving compared with it.

ROCKET EQUATION & MASS

Every tonne you carry costs Δv .

SEMI-MAJOR AXIS

Half the longest width of an orbit. It alone sets the orbital period.

SPHERE OF INFLUENCE (SOI)

The region around Tarn (about 62 km) where Tarn's gravity matters more than Kestrel's.

SYNODIC PERIOD

How long until the same phase angle, and so the same transfer window, comes round again.

TIME WARP

Speeding up mission time (, and .). Warp drops back to 1× before nodes and close approaches.

TOW

Pushing a captured wreck to Tarn Yard. Arrive at Tarn's sphere of influence slower than 300 m/s.

TRANSFER WINDOW

The moment when a single transfer burn will bring you to the target, because the phase angle is right.

TUMBLE

The rotation of a dead spacecraft, in degrees per second.

Δv (DELTA-V)

A change in velocity, in metres per second. Every burn costs Δv , and the tanks hold only so much.

Kestrel, Tarn and every spacecraft in the game are fictional, but the physics is real orbital mechanics, worked at game scale: a 600 km planet with the surface gravity you know (9.81 m/s^2), so that a small tug can reach every wreck.