

Anforderungen für das Situationsbewusstsein von Kampfflugzeugpiloten bei der Luftbetankung mit dem Probe-and-Drogue-Verfahren

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A large, curved image of the Earth from space occupies the bottom half of the slide. It shows the blue atmosphere, white clouds, and green and brown landmasses. The text 'Wissen für Morgen' is overlaid on the right side of the image.

Wissen für Morgen

Einleitung und Motivation

- Luftbetankung ist ein relevantes Element zur Vergrößerung der Reichweite oder Einsatzdauer von militärischen Luftfahrzeugen
- Piloten bekommen aktuell kaum Unterstützung durch Assistenz oder Automatisierung und müssen diesen Vorgang alleine mit fliegerischem Können und Erfahrung durchführen
- Projekt F(AI)²R
 - Forschung zu automatisierter und assistierter Luftbetankung
 - Aufbau eines Kampfflugzeugsimulators
 - Wehrtechnische Forschung für BMVg
 - Geplante Laufzeit bis 03/2023

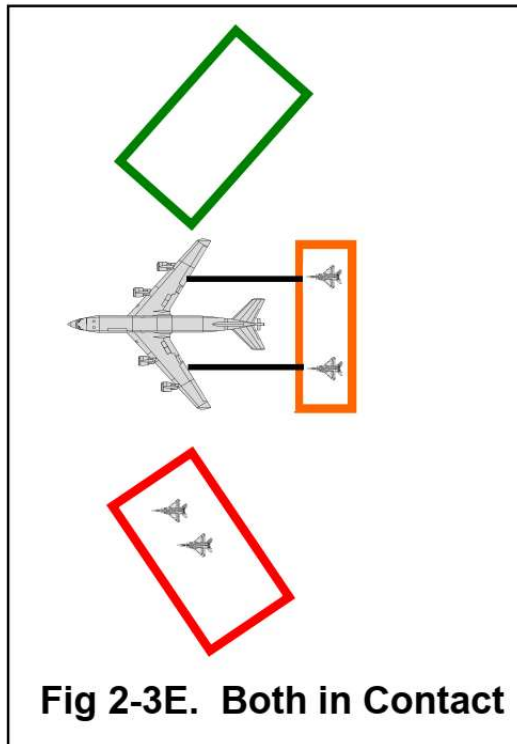


[1]



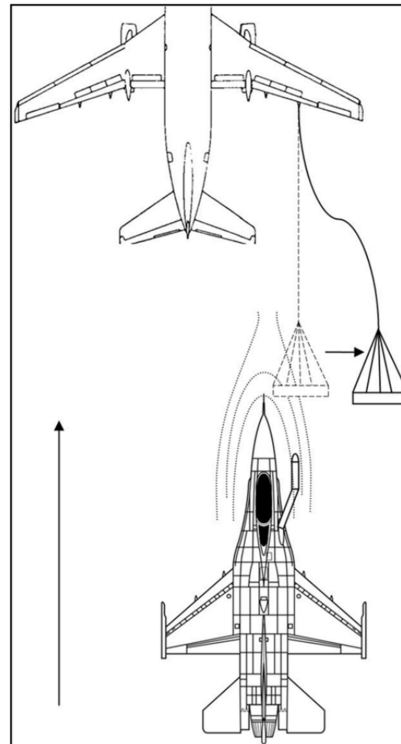
Einführung Luftbetankung mit Probe- and-Drogue-Verfahren

Rendez-Vous und Pre-Contact



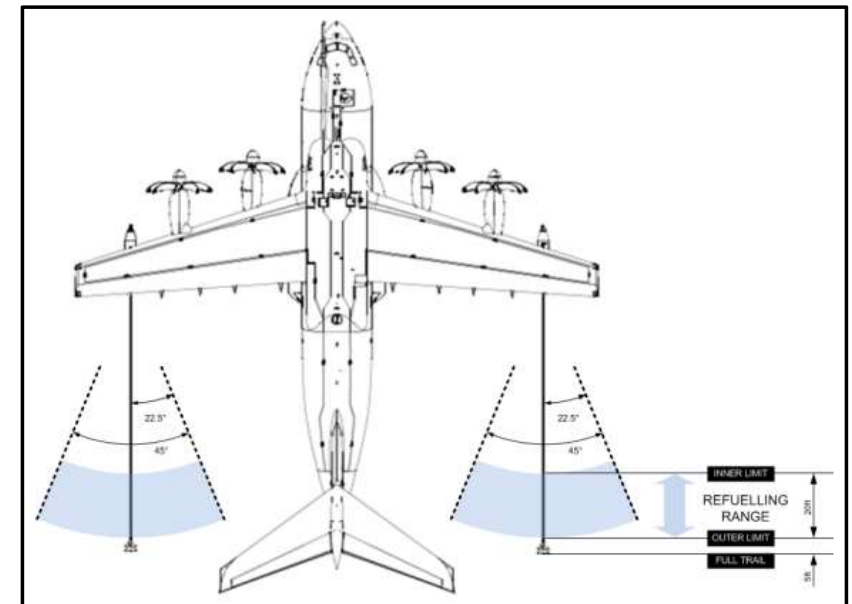
[2]

Kontakt herstellen



[3]

Kontakt halten

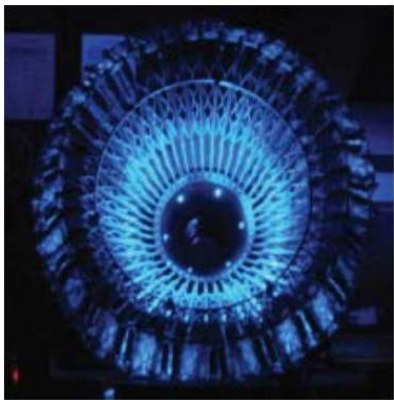


[4]



Aktuelle Unterstützung zum Kontaktherstellen und -halten

Beleuchteter Korb



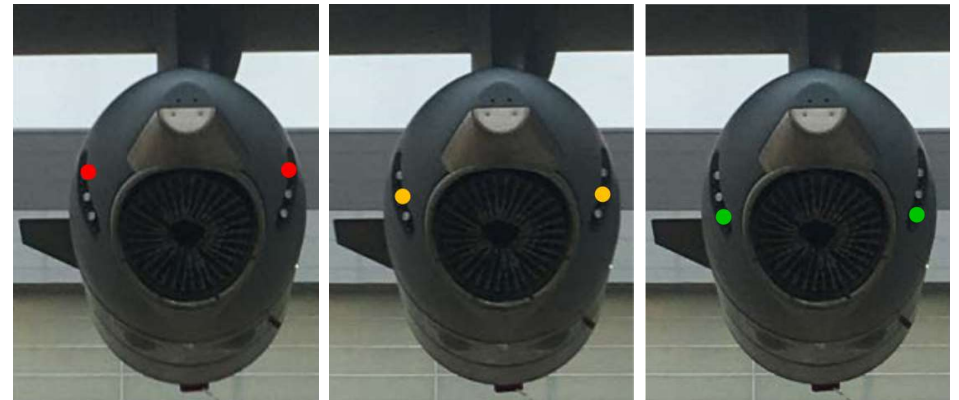
[4]

Referenzmarkierungen



[5]

Pod-Lights



[4]

Schlauchmarkierungen



[Ausschnitt aus 4]



Situational Awareness Requirements Analysis

- ≡ **Strukturierte Methode zur Anforderungsanalyse** in Anlehnung an Mica Endsley [6, 7, 8, 9, 10]
 - Identifikation relevanter Anforderungen in Bezug auf Situational Awareness
 - Startwert zur iterativen Entwicklung von Assistenzsystemen



Piloteninterviews in Kooperation mit dem Kommando Luftwaffe

- Semistrukturierte Interviews
- April - Juni 2021
- In Kooperation mit Kommando Luftwaffe
- Stichprobe
 - 16 männliche Probanden
 - 6 Tornado-Piloten, 10 Eurofighter-Piloten
 - 29-42 Jahre
 - 300-3500 Gesamtflugstunden
 - Flugschüler, Fluglehrer, Geschwaderpiloten

„Das Rendezvous mit dem Tanker ist hergestellt, Sie sind „cleared for tanking“, was machen Sie?“

„Beschreiben Sie in Ihren eigenen Worten wie Sie den Kontakt mit dem Betankungskorb herstellen.“

„In welcher Phase haben Sie bei der Luftbetankung die höchste Belastung (kognitiv/körperlich)?“



Piloten nutzen unterschiedliche Referenzen und Strategien

Rahmenstruktur

Referenzstreifen

Schlauchtrommel und Unterkante Pod

Sprengschnur

Diverse fixe
Markierungen
im HUD

G-Meter

Speichen
des Korbes

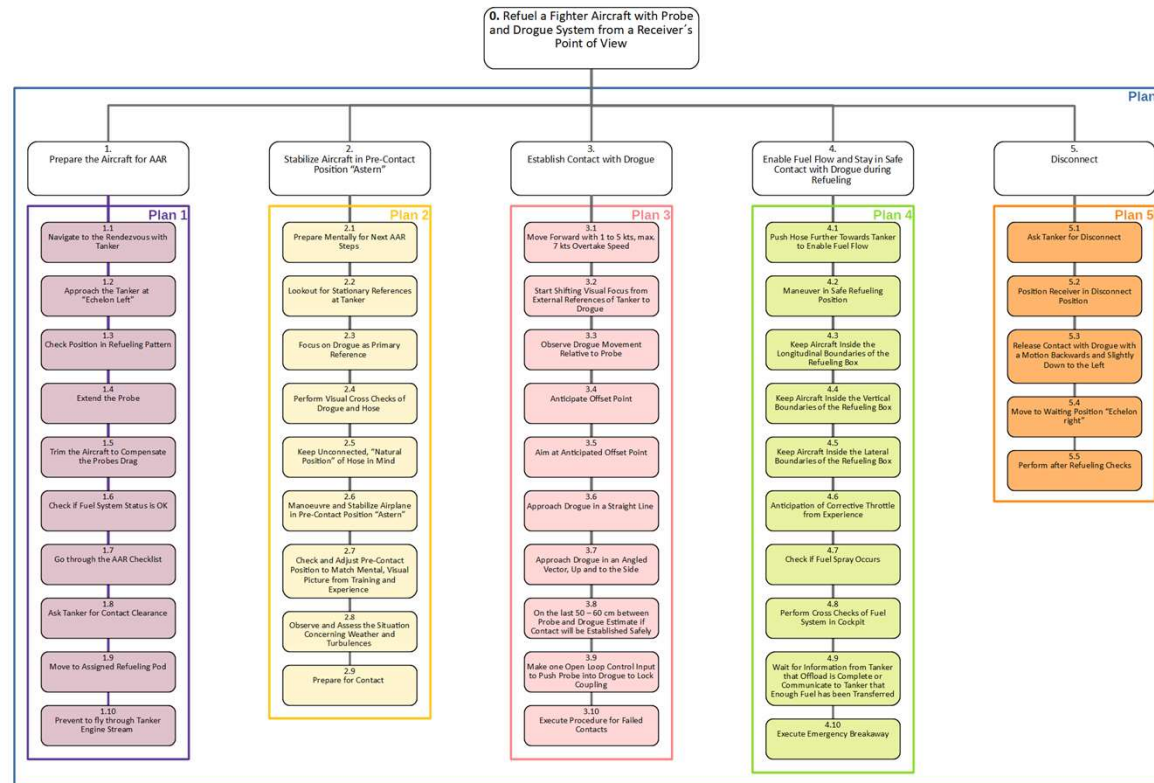
Rumpf und
Leitwerke



Wichtige Erkenntnis:
schräge oder gerade
Anflugstrategie

Beispiel: PA-200 Tornado beim Kontaktherstellen an einem A400M [11]

Hierarchische Aufgabenanalyse (HTA) – Gliederungsebene 1



Plan 0: Do 1, then 2, then 3, then 4, then 5.

Plan 1: Do 1.1, then 1.2, then 1.3, then 1.4, if necessary 1.5, then 1.6, then 1.7, then 1.8, then 1.9, then 1.10.

Plan 2: Do 2.1, then 2.2 or 2.3, then 2.4, then 2.5, then 2.6, then 2.7, then 2.8, then 2.9.

Plan 3: Do 3.1 and maintain and if focus is still on tanker references do 3.2 simultaneously, then 3.3, then 3.4, then 3.5, if straight contact strategy is preferred do 3.6, if oblique contact strategy is preferred do 3.7, then 3.8, then 3.9. If AAR status is critical, AAR status indication lights flash red or safe contact can't be established do 3.10. then Task 2.

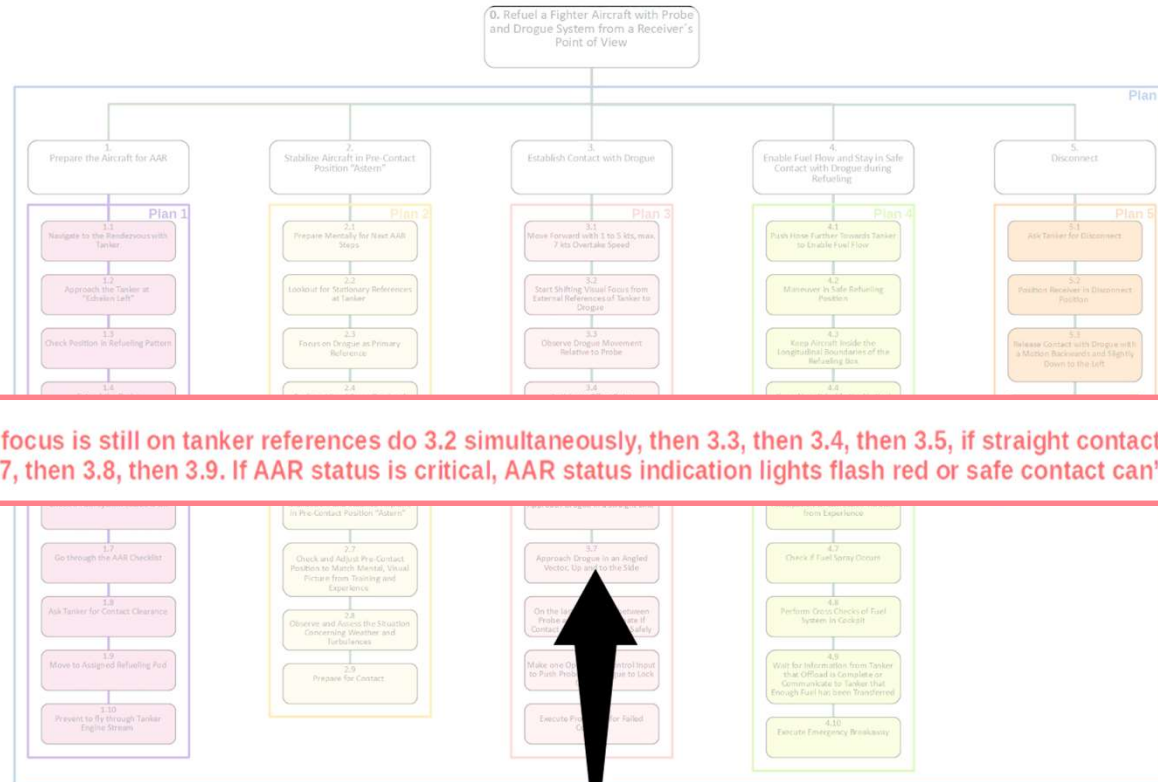
Plan 4: Do 4.1, then 4.2, then 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9 simultaneously. If fuel spray occurs (4.7) consider pushing hose further towards tanker or follow Plan 4.10. then Task 2 if AAR status is critical or breakaway is commanded do 4.10 then Task 2.

Plan 5: Do 5.1, then 5.2, then 5.3, then 5.4, then 5.5, then 5.6.

Vorgehen nach [12, 13]



Hierarchische Aufgabenanalyse (HTA) – Gliederungsebene 1



Plan 0: Do 1, then 2, then 3, then 4, then 5.

Plan 1: Do 1.1, then 1.2, then 1.3, then 1.4, if necessary 1.5, then 1.6, then 1.7, then 1.8, then 1.9, then 1.10.

Plan 2: Do 2.1, then 2.2 or 2.3, then 2.4, then 2.5, then 2.6, then 2.7, then 2.8, then 2.9.

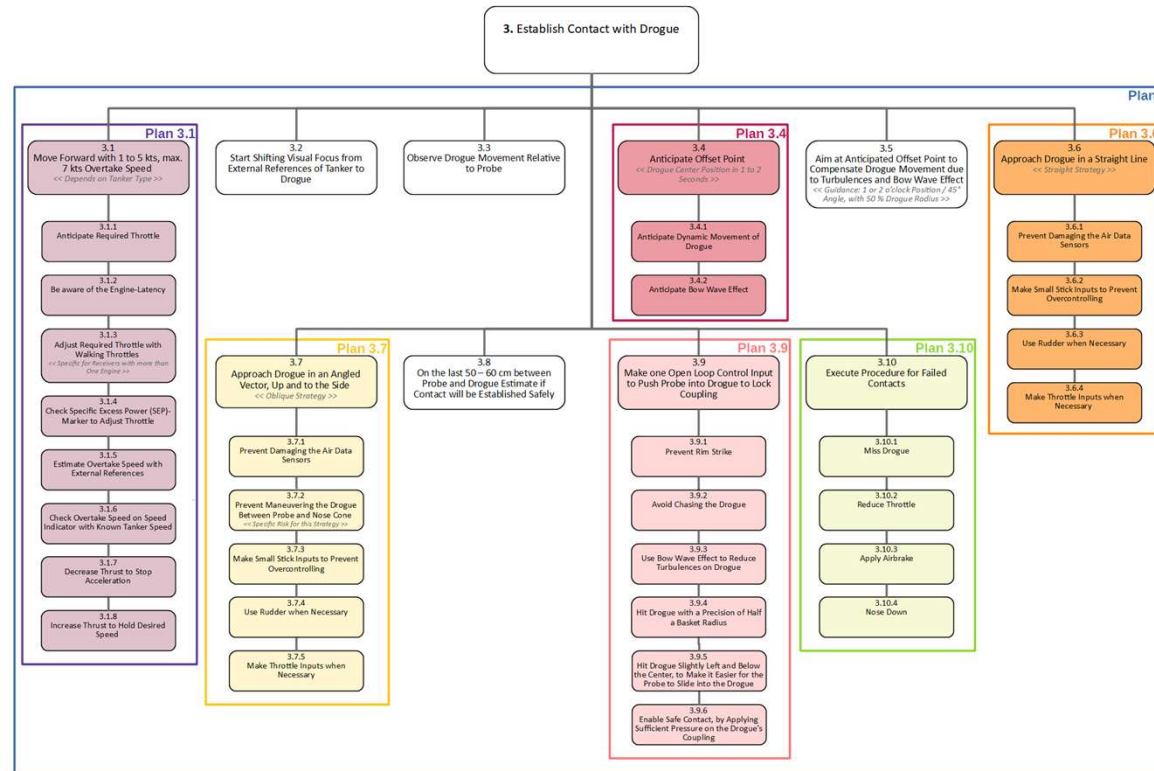
Plan 3: Do 3.1 and maintain and if focus is still on tanker references do 3.2 simultaneously, then 3.3, then 3.4, then 3.5, if straight contact strategy is preferred do 3.6, if oblique contact strategy is preferred do 3.7, then 3.8, then 3.9. If AAR status is critical, AAR status indication lights flash red or safe contact can't be established do 3.10. then Task 2.

Plan 4: Do 4.1, then 4.2, then 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9 simultaneously. If fuel spray occurs (4.7) consider pushing hose further towards tanker or follow Plan 4.10. then Task 2 if AAR status is critical or breakaway is commanded do 4.10 then Task 2.

Plan 5: Do 5.1, then 5.2, then 5.3, then 5.4, then 5.5, then 5.6.



Hierarchische Aufgabenanalyse (HTA) – Gliederungsebene 2



Plan 3: Do 3.1 and maintain and if focus is still on tanker references do 3.2 simultaneously, then 3.3, then 3.4, then 3.5, if straight contact strategy is preferred do 3.6, if oblique contact strategy is preferred do 3.7, then 3.8, then 3.9. If AAR status is critical, AAR status indication lights flash red or safe contact can't be established do 3.10. then Task 2.

Plan 3.1: Do 3.1.1, then 3.1.2, then 3.1.3, if SEP-Marker is available 3.1.4, then 3.1.5 or 3.1.6 or both, then 3.1.7, then 3.1.8.

Plan 3.4: Do 3.4.1 and 3.4.2 simultaneously.

Plan 3.6: Do 3.6.1, 3.6.2, 3.6.3 and 3.6.4 simultaneously.

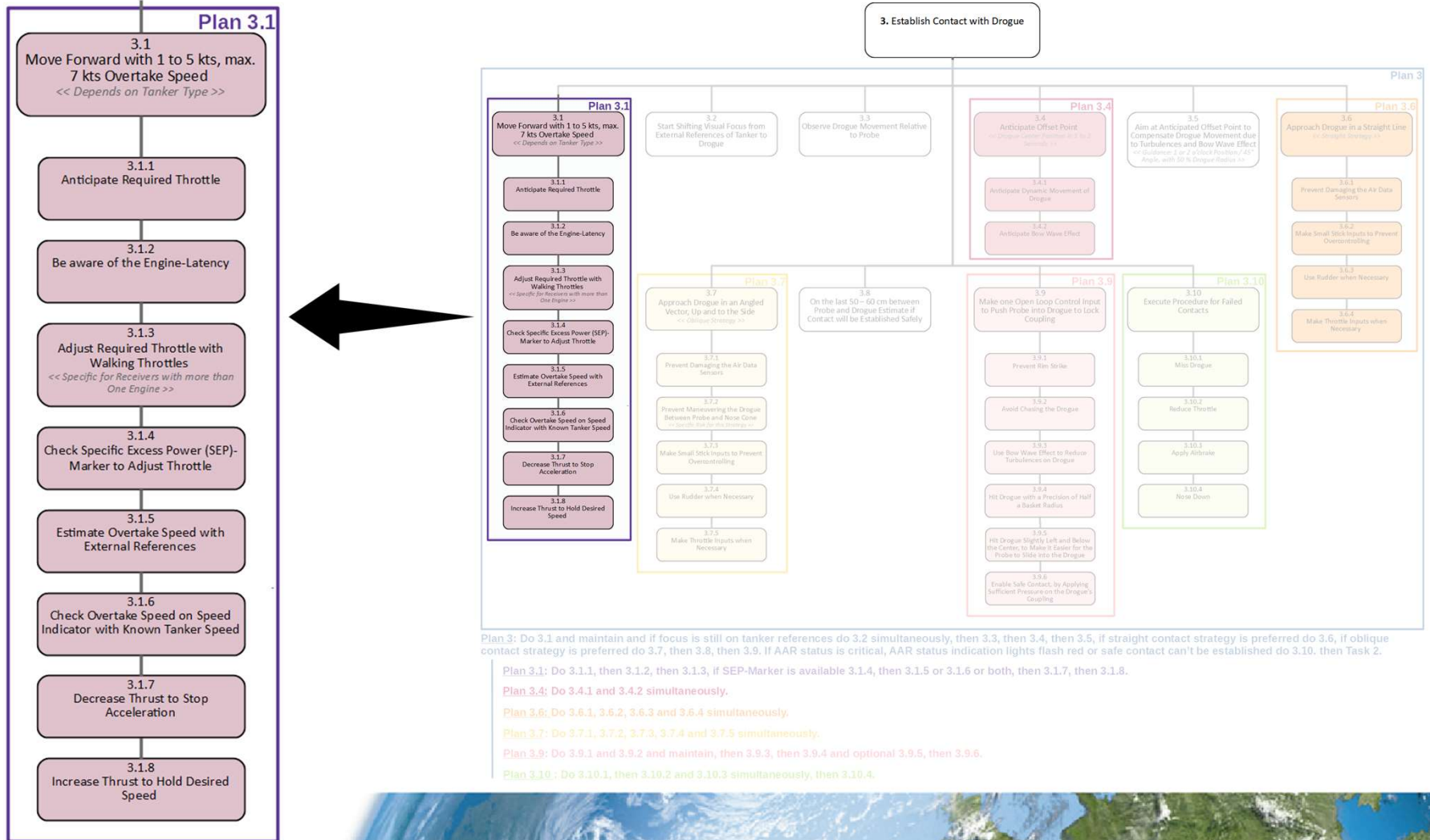
Plan 3.7: Do 3.7.1, 3.7.2, 3.7.3, 3.7.4 and 3.7.5 simultaneously.

Plan 3.9: Do 3.9.1 and 3.9.2 and maintain, then 3.9.3, then 3.9.4 and optional 3.9.5, then 3.9.6.

Plan 3.10: Do 3.10.1, then 3.10.2 and 3.10.3 simultaneously, then 3.10.4.



Hierarchische Aufgabenanalyse (HTA) – Gliederungsebene 3



Situational Awareness Requirements

“ ... dynamic information needs associated with the major goals or sub-goals of the controller in performing his or her job.” – M. Endsley

[7, 8]

Im Rahmen dieser Studie:

- Was muss der Pilot idealerweise wissen, um die entsprechende Aufgabe (Task) oder Unteraufgabe (Subtask) erfüllen zu können?
- Fokus auf dynamische Parameter und relevante statische Informationen, die spezifisch für die Aufgabe oder Unteraufgabe sind



Hinweis:

Beim Ableiten von Anforderungen
die Sprache der Piloten verwenden

→ Englisch



64 SA-Requirements für Pilotenbewertung

| Level 1 | | Level 2 | | Level 3 |
|--|--|---|--|---|
| Perception of the elements in the environment | | Comprehension of the current situation | | Projection of future status |
| Human Ressources | Aircraft Parameters | Current Deviation (Probe to Drogue) | Aircraft Parameters | Future Deviation |
| Personal Experience with AAR | A/C Attitude | Current Lateral Deviation (Probe to Drogue) | EMCON Level | Anticipated Deviation (Lateral/Vertical, Probe to Drogue) |
| Tanker Crew Experience | Remaining Fuel on board | Current Vertical Deviation (Probe to Drogue) | Engine Dynamics / Latency | Effect of Bank Angle on Probe |
| Personal Fatigue | Refuelling Altitude | Current Distance (Probe to Drogue) | Engine Performance / Available Thrust | Projection |
| High Stress Level | A/C Heading | Refuelling Zone | Relative Position to Tanker | Anticipated Position of Drogue |
| Tanker Parameter | A/C gross weight (A/C + Additional Weight, e.g. Fuel, Weapons etc.) | Longitudinal Position within Refuelling Box | Specific Excess Power (SEP) (A/C Energy Increase / Decrease) | Bow Wave Effect |
| Tanker References (e.g. Wings, Fuselage, Horizontal and Vertical Stabilizer, Alignment Stripes, AAR Pod) | Fuelsystem Status (e.g. Fuel Limits, Malfunctions) | Vertical Position within Refuelling Box | AAR Equipment/Parameter | Anticipation of Successful/ Unsuccessful Contact |
| Flow Field Behind Tanker (e.g. Vortex Wakes, Turbulence Field, Exhaust Stream) | AAR Equipment/Parameter | Lateral Position within Refuelling Box | Netto Fuel Flow (Treibstoffaufnahme beim Tanken abzüglich Treibstoffverbrauch) | Anticipated Attitude of Tanker |
| Tanker Speed | Fuel Flow | Boundaries of Refuelling Box | Centre of Oscillations of Drogue | Navigation / Flight Guidance |
| Tanker Attitude | Contact Status of Probe and Drogue | Aircraft Control | Mechanical Loads on Probe | Time till Next Turn in Refuelling Pattern |
| Tanker Type | Occurrence of Fuel Spray | Excessive Flight Control Inputs (Übermäßige Steuereingaben des Piloten) | Refuelling Time Remaining | Geographical Position after AAR |
| Environment | Pod Lights | PIO Warning (Warnung bei einsetzender PIO) | Relative Speeds | |
| Prevailing Visibility | Rotation Rate of Hose Reel (Drehbewegung der Schlauchtrommel im Pod) | Required Thrust for current Flight Task | Overtake Speed (Relativgeschwindigkeit zum Tanker) | |
| Day or Night Conditions | Current Position of Drogue | Trim Status | Maximum Overtake Speed (Maximale Relativgeschwindigkeit zum Tanker) | |
| Outside Air Temperature | Oscillation of Drogue | Navigation / Flight Guidance | Minimum Overtake Speed (Minimale Relativgeschwindigkeit zum Tanker) | |
| Turbulence | Breakaway Signal | Position in Refuelling Pattern | | |
| Horizon Line | Hose Shape (Biegung und Durchhang des Schlauches) | Location of Pre-Contact Position | | |
| | Markings on Hose | Location of Ideal Disconnect Position | | |



64 SA-Requirements für Pilotenbewertung

| Level 1 | | Level 2 | | Level 3 |
|---|--|---|--|---|
| | | Comprehension of the current situation | | Projection of future status |
| Relative Speeds | | <u>Deviation (Probe to Drogue)</u> | <u>Aircraft Parameters</u> | <u>Future Deviation</u> |
| Overtake Speed (Relativgeschwindigkeit zum Tanker) | | Lateral Deviation (Probe to Drogue) | EMCON Level | Anticipated Deviation (Lateral/Vertical, Probe to Drogue) |
| Maximum Overtake Speed (Maximale Relativgeschwindigkeit zum Tanker) | | Vertical Deviation (Probe to Drogue) | Engine Dynamics / Latency | Effect of Bank Angle on Probe |
| Minimum Overtake Speed (Minimale Relativgeschwindigkeit zum Tanker) | | Distance (Probe to Drogue) | Engine Performance / Available Thrust | <u>Projection</u> |
| | | <u>Refuelling Zone</u> | Relative Position to Tanker | Anticipated Position of Drogue |
| | | Position within Refuelling Box | Specific Excess Power (SEP) (A/C Energy Increase / Decrease) | Bow Wave Effect |
| | | Position within Refuelling Box | <u>AAR Equipment/Parameter</u> | Anticipation of Successful/ Unsuccessful Contact |
| | | Position within Refuelling Box | Netto Fuel Flow (Treibstoffaufnahme beim Tanken abzüglich Treibstoffverbrauch) | Anticipated Attitude of Tanker |
| | | Position within Refuelling Box | Centre of Oscillations of Drogue | <u>Navigation / Flight Guidance</u> |
| | | Position within Refuelling Box | Mechanical Loads on Probe | Time till Next Turn in Refuelling Pattern |
| | | Position within Refuelling Box | Refuelling Time Remaining | Geographical Position after AAR |
| Environment | Occurrence of Fuel Spray | Excessive Flight Control Inputs (Übermäßige Steuereingaben des Piloten) | Relative Speeds | |
| Prevailing Visibility | Pod Lights | PIO Warning (Warnung bei einsetzender PIO) | Overtake Speed (Relativgeschwindigkeit zum Tanker) | |
| Day or Night Conditions | Rotation Rate of Hose Reel (Drehbewegung der Schlauchtrommel im Pod) | Required Thrust for current Flight Task | Maximum Overtake Speed (Maximale Relativgeschwindigkeit zum Tanker) | |
| Outside Air Temperature | Current Position of Drogue | Trim Status | Minimum Overtake Speed (Minimale Relativgeschwindigkeit zum Tanker) | |
| Turbulence | Oscillation of Drogue | <u>Navigation / Flight Guidance</u> | | |
| Horizon Line | Breakaway Signal | Position in Refuelling Pattern | | |
| | Hose Shape (Biegung und Durchhang des Schlauches) | Location of Pre-Contact Position | | |
| | Markings on Hose | Location of Ideal Disconnect Position | | |





Bewertung der Relevanz der SA-Requirements

- Online-Matrixabfrage
- N = 14 Piloten
- Juni – August 2021
- Dauer ~ 30 min

*
Wie relevant ist für Sie der Parameter **"Tanker Speed"**?

| | nicht relevant | wenig relevant | mittelmäßig relevant | ziemlich relevant | sehr relevant | keine Antwort |
|--------------------|-----------------------|-----------------------|----------------------------------|-----------------------|----------------------------------|-----------------------|
| | 1 | 2 | 3 | 4 | 5 | |
| Pre-Contact | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Kontakt herstellen | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> |
| Kontakt halten | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> |
| Kontakt lösen | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

? Bitte bewerten Sie in der Matrix die Relevanz des oben genannten Parameters entsprechend der Skala und in Abhängigkeit der Phasen der Luftbetankung. Wenn Ihnen der Parameter unbekannt ist, wählen Sie bitte die Option "Keine Antwort" aus.



Auszug aus dem SA-Requirements-Ranking

1 = nicht relevant
5 = sehr relevant

| Kontakt herstellen | | |
|--------------------|--|------------|
| Rang | Item | Mittelwert |
| 1 | Turbulence | 4,86 |
| 2 | Personal Experience with AAR | 4,71 |
| 3 | High Stress Level | 4,57 |
| 4 | Oscillation of Drogue | 4,50 |
| 5 | Current Vertical Deviation (Probe to Drogue) | 4,50 |
| 6 | Overtake Speed | 4,43 |
| 7 | Personal Fatigue | 4,43 |
| 8 | Current Distance (Probe to Drogue) | 4,36 |
| 9 | Contact Status of Probe and Drogue | 4,31 |
| 10 | Day or Night Conditions | 4,31 |



Zusammenfassung und Fazit

Anwenden und Erweitern des Verfahrens von Mica Endsley für den Vorgang der Luftbetankung

Schaffung einer umfangreichen Datenbasis zur Luftbetankung mit dem Probe-and-Drogue-Verfahren mit Kampfflugzeugen

Identifikation relevanter Anforderungen für das Situationsbewusstsein von Piloten

→ Grundlage zur Entwicklung von Assistenzsystemen zur Luftbetankung



Vielen Dank!



Kontakt

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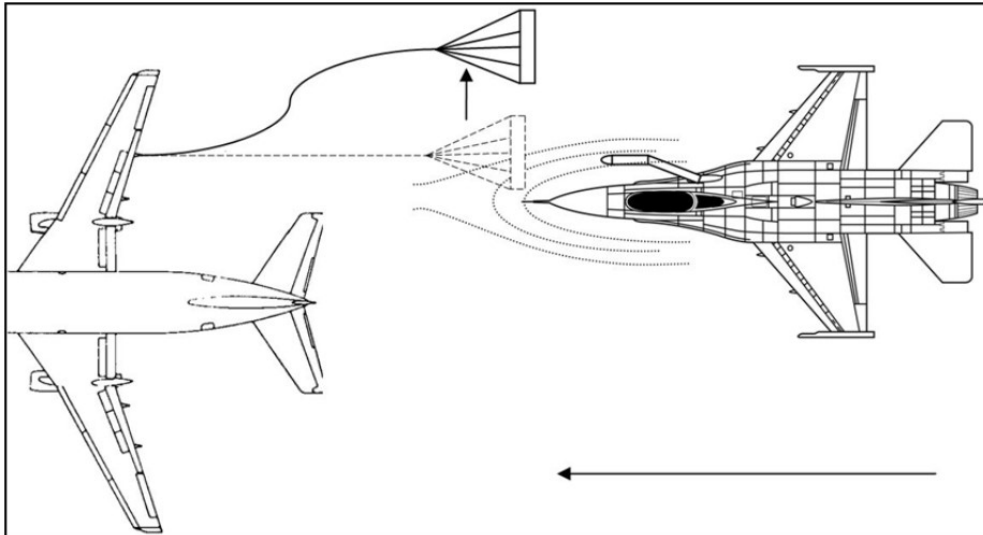


Literaturquellen

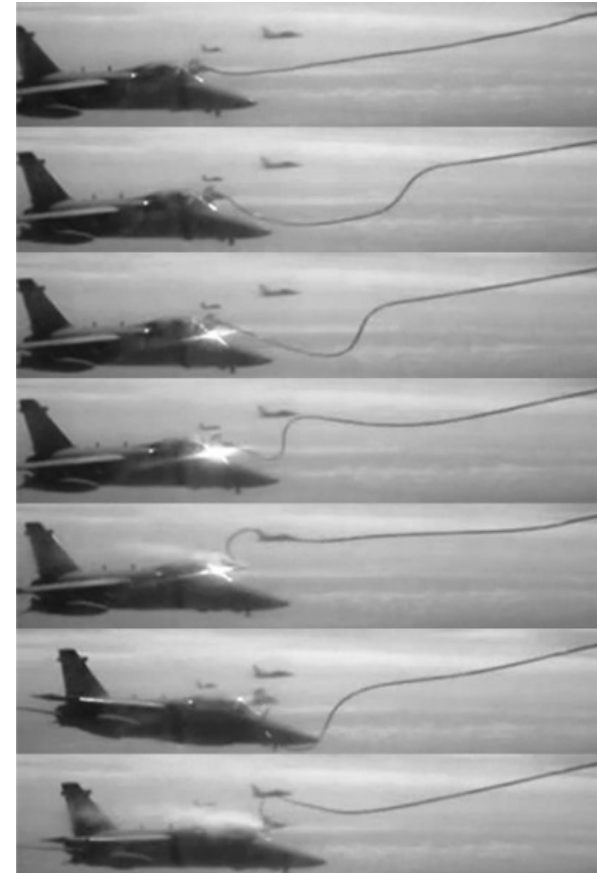
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Luftbetankung – Besondere Herausforderungen und Gefahren



[3]



[14]



Pod Light Signals

| OVERT | <u>Receiver not connected</u> | COVERT | <u>Receiver connected</u> | COVERT |
|-------|--|--------|---|--------|
| | Do not make contact Permissible to be astern the refueling station | | Normal disconnect Permissible to be astern the refueling station | |
| | Hose ready May contact | | Forward of refueling range (Flashing) | |
| | Do not make contact | | Aft of refueling range | |
| | | | In refueling range Fuel is flowing | |
| | | | In refueling range Fuel is <u>not</u> flowing (Pulsing) | |
| | | | Disconnect immediately "BREAK AWAY" (Flashing for 10s then steady) | |



Ungekürzte SA-Requirements Parameter Liste

| Level 1 | | Level 2 | | Level 3 |
|--|--|---|--|---|
| Perception of the elements in the environment | | Comprehension of the current situation | | Projection of future status |
| Aircraft Data | Aircraft Parameters | Current Deviation (Probe to Drogue) | Aircraft Parameters | Future Deviation |
| A/C Type | A/C Attitude | Current Lateral Deviation (Probe to Drogue) | A/C Malfunctions | Anticipated Deviation (Lateral/Vertical, Probe to Drogue) |
| A/C Envelope | Remaining Fuel on board | Current Vertical Deviation (Probe to Drogue) | Status of Wingmen (Fuel Status, Malfunctions, ...) | Anticipated Deviation (Longitudinal, Probe to Drogue) |
| Maximum Extraction Speed of Probe | Refueling Altitude | Current Longitudinal Deviation (Probe to Drogue) | EMCON Level | Anticipated Relative Attitude to Tanker |
| Human Ressources | A/C Heading | Current Distance (Probe to Drogue) | Engine Dynamics / Latency | Effect of Bank Angle on Probe |
| Personal Experience with AAR | Status of Probe | Current Relative Attitude to Tanker | Engine Performance / Available Thrust | Projection |
| Personal Experience on A/C Type | A/C gross weight (A/C + Additional Weight, e.g. Fuel, Weapons etc.) | Human Ressources | Relative Position to Tanker | Anticipated Position of Drogue |
| Tanker Crew Experience | Occurrence of Malfunction Messages | Confidence Level in Wingman | Specific Excess Power (SEP) (A/C Energy Increase / Decrease) | Anticipated Movement of Drogue |
| Wingmen Experience | Fuelsystem Status (e.g. Fuel Limits, Malfunctions) | Confidence Level in Tanker Crew | Environment | Bow Wave Effect |
| Personal Fatigue | Environment | Workload of Wingman / Tanker Crew | Impacts of Weather/ Turbulence | Offset Point /Aiming Area |
| High Stress Level | Prevailing Visibility | Personal Ability to Perform the Mission | Occurrence of Dangerous Situation | Impact of Dangerous Situation |
| Alertness | Day or Night Conditions | Tanker Parameters | AAR Equipment/Parameter | Change of Refueling Altitude Required because of Weather |
| Time on Duty | Outside Air Temperature | Tanker Attitude | Netto Fuel Flow (Treibstoffaufnahme beim Tanken abzüglich Treibstoffverbrauch) | Change in AAR Strategy because of Weather |
| Starting Point of Spatial Disorientation | Turbulence | Refueling Zone | Targeted Contact Zone (50% of Basket) | Anticipation of Successful/ Unsuccessful Contact |
| Tanker Parameter | Horizon Line | Longitudinal Position within Refuelling Box | Centre of Oscillations of Drogue | Anticipated Attitude of Tanker |
| Tanker References (e.g. Wings, Fuselage, Horizontal and Vertical Stabilizer, Alignment Stripes, AAR Pod) | AAR Equipment/Parameter | Vertical Position within Refueling Box | Mechanical Loads on Probe | Navigation / Flight Guidance |
| Refueling System Status | Fuel Flow | Lateral Position within Refueling Box | Refueling Time Remaining | Time till Next Turn in Refueling Pattern |
| Flow Field Behind Tanker (e.g. Vortex Wakes, Turbulence Field, Exhaust Stream) | Contact Status of Probe and Drogue | Required Corrective Manoeuvres within Refuelling Zone | Relative Speeds | Geographical Position after AAR |
| Condition of Tanker | Occurrence of Fuel Spray | Boundaries of Refuelling Box | Overtake Speed (Relativgeschwindigkeit zum Tanker) | |
| Tanker Heading | Pod Lights | Aircraft Control | Maximum Overtake Speed (Maximale Relativgeschwindigkeit zum Tanker) | |
| Tanker Speed | Rotation Rate of Hose Reel (Drehbewegung der Schlauchtrommel im Pod) | Excessive Flight Control Inputs (Übermäßige Steuereingaben des Piloten) | Minimum Overtake Speed (Minimale Relativgeschwindigkeit zum Tanker) | |
| Tanker Attitude | Current Position of Drogue | PIO Warning (Warnung bei einsetzender PIO) | Relative Lateral Speed to Tanker | |
| Tanker Type | Oscillation of Drogue | Required Thrust for current Flight Task | Relative Vertical Speed to Tanker | |
| | Breakaway Signal | Required Throttle Input | Navigation / Flight Guidance | |
| | Hose Shape (Biegung und Durchhang des Schlauches) | Required Stick Input | Position in Refuelling Pattern | |
| | Condition of AAR-Equipment | Trim Status | Assigned Tanker | |
| | Markings on Hose | | Location of Pre-Contact Position | |
| | | | Location of Ideal Disconnect Position | |



Auszug aus dem SA-Requirements-Ranking

| Kontakt herstellen | | | | |
|--------------------|--|----|------------|-----------------|
| Rang | Item | N | Mittelwert | Std.-Abweichung |
| 1 | Turbulence | 14 | 4,86 | 0,363 |
| 2 | Personal Experience with AAR | 14 | 4,71 | 0,469 |
| 3 | High Stress Level | 14 | 4,57 | 0,646 |
| 4 | Oscillation of Drogue | 14 | 4,50 | 0,941 |
| 5 | Current Vertical Deviation (Probe to Drogue) | 14 | 4,50 | 0,760 |
| 6 | Overtake Speed | 14 | 4,43 | 0,756 |
| 7 | Personal Fatigue | 14 | 4,43 | 0,514 |
| 8 | Current Distance (Probe to Drogue) | 14 | 4,36 | 0,842 |
| 9 | Contact Status of Probe and Drogue | 13 | 4,31 | 1,032 |
| 10 | Day or Night Conditions | 13 | 4,31 | 0,751 |

