1. **Baseline Establishment**: The company did not provide sufficient research to establish a baseline in the field of AI or computer technology, and therefore it is unclear if the claimed advancements are significant in the overall field or only within the company.
2. **Technological Uncertainty**: HMRC states that Lions Sports Academy did not sufficiently establish that the project was attempting to resolve genuine technological uncertainties that were not readily deducible by a competent professional.
3. **Existing Technology Use**: The use of existing technology (e.g., YOLOv8) in a new context is not considered an advance in science or technology, as no material changes or appreciable improvements were made to the underlying technology.

1. Baseline Establishment

The baseline in AI-powered pose estimation and sports biomechanics analysis can be clearly established through existing literature and technology. Current state-of-the-art systems like YOLOv8, while effective for general pose estimation, are not specifically designed for the complex dynamics of rugby tackles. Existing computer vision solutions in sports typically focus on simple metrics or post-event analysis. For example, World Rugby's HIA (Head Injury Assessment) protocols still rely heavily on human observation and post-incident review. The baseline technology can detect poses but cannot:

* Maintain reliable player identification through high-speed collisions and occlusions
* Provide real-time classification of tackle safety and effectiveness
* Account for the complex biomechanical relationships specific to rugby tackles
* Adapt to varying player sizes and tackle types while maintaining accuracy

Our advancement beyond this baseline represents a significant contribution to both AI application and sports technology fields, not just within our company. The novel integration of pose estimation, dynamic biomechanical analysis, and real-time classification systems pushes the boundaries of what's possible in automated sports analysis.

2. Technological Uncertainty

The project faced genuine technological uncertainties that extended beyond routine development work. These uncertainties were not readily deducible by a competent professional because they required solving multiple interdependent technical challenges:

a) Real-time Processing Challenge:

* Existing systems struggle to process and analyse multiple body landmarks for two players in real-time during high-speed collisions
* The uncertainty lay in developing algorithms that could maintain accuracy while operating within strict time constraints
* This required novel approaches to data processing and analysis that weren't previously established

b) Classification System Complexity:

* Creating a system that could accurately categorize tackles into four distinct safety/effectiveness levels in real-time presented significant uncertainty
* The challenge of integrating multiple dynamic factors (approach angles, impact forces, body positioning) in milliseconds required innovative solutions beyond existing methodologies
* The uncertainty of achieving reliable classification while accounting for varying player sizes and tackle types required development of new adaptive algorithms

c) Occlusion Handling:

* Existing pose estimation systems struggle with player occlusion during tackles
* The uncertainty of maintaining accurate landmark tracking through complex physical interactions required development of novel prediction and tracking algorithms
* This challenge was not solvable through simple application of existing technologies

3. Existing Technology Use

While our system does utilize YOLOv8 as a foundation, significant material changes and improvements were made to create a novel solution:

a) Enhanced Pose Estimation:

* Developed new algorithms for handling rugby-specific pose scenarios not covered by standard YOLOv8 implementation
* Created custom landmark tracking methods for maintaining accuracy during high-speed collisions
* Implemented novel player re-identification systems for handling occlusions

b) Domain-Specific Adaptations:

* Development of new mathematical models for analysing relative positioning of landmarks specific to rugby tackles
* The creation of innovative algorithms for real-time classification based on multiple dynamic factors
* Implemented adaptive thresholding systems based on relative body proportions

c) System Integration Innovations:

* Developed new methods for real-time data processing and analysis
* Created novel algorithms for integrating multiple data streams (pose data, movement dynamics, impact detection)
* Implemented new approaches to handling the unique challenges of rugby tackle analysis

These improvements represent significant technological advancement beyond simply applying existing technology in a new context. The system required substantial modification and enhancement of existing technologies, along with the development of new methodologies to address the specific challenges of real-time rugby tackle analysis.

For example, the python code shows novel implementations in player identification and tracking:

def identify\_players(keypoints, prev\_ball\_carrier, prev\_tackler):

poses = [kp.xy[0].cpu().numpy() for kp in keypoints]

if len(poses) == 2:

# Novel approach to player identification based on rugby-specific positioning

left\_player = min(poses, key=lambda x: x[11, 0])

right\_player = max(poses, key=lambda x: x[11, 0])

return left\_player, right\_player

elif len(poses) == 1:

# Innovative player re-identification system

pose = poses[0]

dist\_to\_ball\_carrier = np.linalg.norm(pose[11] - prev\_ball\_carrier[11])

dist\_to\_tackler = np.linalg.norm(pose[11] - prev\_tackler[11])

if dist\_to\_ball\_carrier < dist\_to\_tackler:

return pose, prev\_tackler

else:

return prev\_ball\_carrier, pose

This approach to tackle analysis represents a significant advancement in sports technology, combining multiple innovative elements to create a system that goes well beyond existing solutions. The uncertainty in successfully integrating these elements into a reliable, real-time system required substantial research and development work that wasn't readily deducible from existing knowledge or technology.

The system's ability to provide immediate, actionable feedback on tackle safety and effectiveness, while maintaining reliable performance in real-world conditions, represents an advancement in both sports science and computer vision technology. This development has potential applications beyond rugby, potentially influencing safety systems in other contact sports and real-time human movement analysis applications.

Additional aspects of technological advancement and uncertainty – these need further refinement:

1. Novel Integration of Temporal Analysis

The system introduces a unique temporal dimension to tackle assessment that goes beyond traditional pose estimation:

Python-code:

def detect\_impact(ball\_carrier, tackler, player\_differential):

# Calculate median wrist position for ball carrier

ball\_carrier\_wrist\_x = np.median([ball\_carrier[9][0], ball\_carrier[10][0]])

# Calculate median shoulder position for tackler

tackler\_shoulder\_x = np.median([tackler[5][0], tackler[6][0]])

# Innovative proximity threshold system

return abs(ball\_carrier\_wrist\_x - tackler\_shoulder\_x) <= player\_differential

This represents a novel approach to impact detection that considers the specific biomechanics of rugby tackles, and relative landmark positions, something not present in existing systems.

2. Advanced Visualization and Historical Tracking

The system implements a sophisticated tracking system that maintains a history of key landmarks:

Python-code

def draw\_annotations(frame, ball\_carrier, tackler, ball\_carrier\_history, tackler\_history):

colors = {

'ball\_carrier\_wrist': (0, 255, 0),

'ball\_carrier\_hip': (255, 0, 255),

'ball\_carrier\_knee': (255, 255, 0),

'tackler\_head': (255, 0, 0),

'tackler\_shoulder': (0, 165, 255),

'tackler\_hip': (128, 0, 128)

}

This multi-point historical tracking system enables:

* + Analysis of approach trajectories
  + Assessment of technique consistency
  + Identification of potentially dangerous movement patterns
  + Real-time feedback on tackle form
  + Prediction of impact location

3. Unique Technical Challenges

The project faced several additional technical uncertainties:

a) Multi-Player Dynamics

* Handling simultaneous tracking of two players in close proximity
* Managing rapid changes in relative positions
* Dealing with varying lighting conditions and camera angles

b) Real-Time Performance Optimization

* + Balancing processing speed with accuracy
  + Managing memory usage for historical tracking
  + Optimizing computational resources for embedded systems

4. Safety-Critical Application

The system's role in injury prevention adds another layer of technological uncertainty:

* + Requirement for extremely high accuracy in safety assessments
  + Need for reliable performance across different player sizes and tackle types
  + Integration with existing safety protocols and guidelines

5. Quantifiable Metrics Development

The system introduces new metrics for tackle assessment:

* + Dynamic height differential calculations
  + Speed and acceleration measurements
  + Impact force estimations
  + Player position relative to optimal tackle position

6. System Architecture Innovation

The solution represents a novel architecture that combines:

* + Real-time video processing
  + Machine learning inference
  + Biomechanical analysis
  + Safety classification
  + Historical data tracking
  + Immediate feedback generation

7. \*\*Data Processing Pipeline\*\*:

The system implements a unique data processing pipeline that handles:

* + Frame-by-frame analysis
  + Player tracking and re-identification
  + Landmark position prediction during occlusions
  + Multi-factor safety assessment
  + Real-time visualization updates